

**Training , Installation and Study
of Ten Solar Photovoltaic
Pumping Systems**

Final Report

submitted to

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Contents

	Page No.
1.0 Photovoltaic Pumping for Rural Water Supply	6
1.1 Pumping needs and conventional technologies for rural water supply	
1.2 The technology	
1.3 Development and current status	
1.3.1 System configurations	
1.3.2 Field programmes	
1.4 Indian programme	
1.5 About the project	
1.5.1 Background	
1.5.2 Objectives	
1.5.3 Scope	
2.0 Site Selection and Installation	21
2.1 Site selection	
2.1.1 Phase 1: Identification of regions and nodal agencies	
2.1.2 Phase 2: Development of site selection criteria and shortlisting of sites	
2.1.3 Phase 3: Finalisation of sites for installation of the PV pumping systems	
2.2 Installation and commissioning of the PV pumping systems	
3.0 Performance and Evaluation	54
3.1 Sub-systems and their operating characteristics	
3.1.1 Photovoltaic modular array	
3.1.2 Inverter	
3.1.3 Motor/pump unit	
3.2 Matching motor/pump and array power output characteristics	
3.3 Specifications of the system used	
3.3.1 PV modules	
3.3.2 DC-to-AC inverter	
3.3.3 Submersible motor/pump unit	
3.4 Methods of evaluation	
3.4.1 Approach 1: Daily output	
3.4.2 Approach 2(a): Overall system energy conversion efficiency	
3.4.3 Approach 2(b): Sub-system efficiency	
3.4.4 Approach 3: Performance at different simulated pumping heads	
3.5 Results and discussions	
3.5.1 Daily water output	
3.5.2 Overall system conversion efficiency and sub-system efficiencies	
3.5.3 Performance at simulated pumping head	

4.0	Social Aspects and Impact Assessment	88
4.1	Approach	
4.1.1	Information collection	
4.1.2	Impact assessment	
4.2	Reliability and availability	
4.3	Acceptability	
4.3.1	Doubts regarding the purity of water: Tlonia	
4.3.2	Unsuitable for irrigation: Golaghati	
4.3.3	Dissatisfaction due to low output: Skkabamin	
4.3.4	Social rivalry: Indrapura	
4.4	Affordability	
4.5	Operation and maintenance	
4.6	Community participation	
4.7	Cost implications	
5.0	Project Assessment	108
5.1	Effectiveness of the approach	
5.1.1	Site selection	
5.1.2	Installation and commissioning	
5.1.3	Performance evaluation	
5.2	Suitability of the device for chosen application	
5.2.1	Technical feasibility	
5.2.2	Socio-economic feasibility	
6.0	Conclusions	125
	References	128

List of Tables

- 1.1 Comparison of pumping technologies.
- 1.2 PV pumping systems configuration and their suppliers.
- 1.3 Supply of system by Grundfos International.
- 1.4 Project objectives and associated activities.

- 2.1 Selected sites for PV pump installation in India.
- 2.2 Selected nodal agencies for co-ordinating the project at local level.
- 2.3 Responses of local agencies.
- 2.4 Details of sites visited in Bihar.
- 2.5 Details of sites visited in Karnataka.
- 2.6 Details of sites visited in Jalna, Maharashtra.
- 2.7 Details of sites visited in Nagpur, Maharashtra.
- 2.8 Details of sites visited in Arunachal Pradesh.
- 2.9 Detailed information on various installations.

- 3.1 Expected water output under $6 \text{ kWh/m}^2/\text{day}$.
- 3.2 Record of daily output data.
- 3.3 Solar radiation data for New Delhi.
- 3.4 Overall system efficiency (instantaneous)
- 3.5 Calculated sub-system efficiencies.
- 3.6 Estimated and received daily water output data from Gual Pahari.
- 3.7 Performance at simulated pumping heads.
- 3.8 Performance at reduced array power.

- 4.1 Details of the communities surveyed.
- 4.2 Cost of pumping from the PV system.
- 4.3 Cost of pumping using diesel motor/pump set.

List of Figures

- Fig. 1.1: Pumpset Configurations**
- Fig. 1.2: World PV Pump Sales (Ref. 10)**
- Fig. 1.3: PV Pumping Systems Supplied by the DNES**
- Fig. 2.1: Commissioned Systems at Seven Sites**
- Fig. 3.1: Power Conversion in PV -Pumping System (Ref. 2)**
- Fig. 3.2: A Typical Day's Operation of a Solar Pump
with Power Conditioning (Ref. 22)**
- Fig. 3.3: I-V Characteristic Curve of PV Array (Ref. 22)**
- Fig. 3.4: A Simple Centrifugal Pump**
- Fig. 3.5: Characteristic Curve for a Single Stage
Centrifugal Pump**
- Fig. 3.6: Characteristic Curves of a Centrifugal Pump at
Various Speed**
- Fig. 3.7: Specifications of Photowatt Module**
- Fig. 3.8: Inverter Cabinet**
- Fig. 3.9: Submersible 4" AC Motor**
- Fig. 3.10: Submersible 4" Multistage Centrifugal Pump**
- Fig. 3.11: Pump Characteristics at 2900 rpm**
- Fig. 3.12: Gual Pahari System Performance**
- Fig. 3.13: Manufacturer's Capacity Diagram**
- Fig. 3.14: Array Performance at Gual Pahari**

List of Annexures

- Annexure 1A: Commercially Available PV Pumping Systems**
- Annexure 2A: Proposal for Installation of a PV Deepwell Water Pumping System**
- Annexure 2B: Workshop Material**
- Annexure 2C: Manufacturer's Specifications**
- Annexure 2D: Site Selection Criterion**
- Annexure 2E: Material Required for PV Pump Installation**
- Annexure 3A: Record Sheet on PV Pumping System**
- Annexure 3B: Instrumentation**
- Annexure 3C: Performance Evaluation (Technical)**
- Annexure 4A: Social Impact Assessment (Organisation's response)**
- Annexure 4B: Social Impact Assessment (User's response)**
- Annexure 4C: Cost Estimate of Installation at Indrapura**

Executive Summary

Sponsored by the Department of Non-conventional Energy sources and conducted by the Tata Energy Research Institute, this study documents field experiences with photovoltaic (PV) water pumping systems donated to India by the French author Mr. Dominique Lapierre. The project, initiated in October 1988 was undertaken to study the performance of these systems in different Indian conditions and their suitability for chosen end-use applications. The scope of the study included installing the systems in regions recommended by the Steering Committee, and monitoring their field performances. Sites were selected on the basis of end-use water requirement and technical compatibility with the system. The systems were considered only for rural water supply applications. Irrigation was not considered as one of the end-uses on account of the limited capacity of the pumping system.

This report discusses site selection, installation and commissioning, technical performance and social impact of these systems on user. It can be used as a reference for similar PV pumping programme in India, as also to initiate programmes in other developing countries.

The Systems

Ten PV pumping systems manufactured and supplied by Photowatt International, France were donated to India under the ASVIN programme executed by the CNRS, France. The PV array comprise of multicrystalline silicon modules manufactured by Photowatt International France; the installed

capacity of the array being 1.28 kW_p. A high efficiency variable frequency inverter, designed and developed by Total Energie, France, converts the DC electricity from the PV array to AC electricity which is fed to the motor/pump unit. A three phase AC motor and multistage centrifugal pump together form a 4 inch diameter submersible motor/pump unit which is suitable to be fitted in a borewell. Nine out of ten systems are designed for lifting water from a total pumping head of 20 m, while one is designed for 50 m. Expected water output as per the supplier's specifications are 70 m³ and 18 m³ respectively from two different designs under 6 kWh/m²/day of solar irradiation.

Site Selection and Installation

A total of seven systems were installed by TERI in different regions of the country to study their performance and impact in varied climatic, topographic and sociological conditions. Execution of the project by TERI was done with the coordination of state level agencies active in identified regions or states for system installations. Site selection criterion, developed gradually after having interactions with concerned nodal agencies at various levels, included the drinking and domestic water requirements of the community, weather characteristics, yield and type of the borewell, open space near the well for installing the array, infrastructure available with the nodal agency and social structure of the community. The first installation was done at the TERI campus in Gual Pahari, Haryana by the project team to

familiarize with the system and installation procedures. Subsequently, the representatives of selected nodal agencies were made to acquaint themselves with the same during a workshop organised by the TERI. The final selection and installation were done by the TERI project team and the staff of nodal agencies after visiting all proposed and shortlisted sites. Table below summarizes the activity.

Site	Implementing Agency	End-Use
Gual Pahari, Haryana	TERI	Water for plantation
Golaghati, Tripura	DSTE	Drinking
Sikkabamin, Arunachal Pradesh	RWD	Drinking
Zirpitanda, Maharashtra	MEDA	Drinking
Tilonia, Rajasthan	SWRC	Domestic except drinking
Indrapura, Rajasthan	REDA	Drinking
Taklahalli, Karnataka	KSCST	Drinking

Two systems were given to Society for Rural Industrialisation Ranchi and one to Minor Irrigation Division, Orissa.

Technical Performance and O&M Aspects

Two years of continuous monitoring of the system commissioned at Gual Pahari, Haryana indicated that the maximum daily mean water output averaged over a month has been 53 m^3 in the month of April 1989. The maximum daily mean output during 1990, also in the month of April, was found to have reduced by ten percent. No technical problem except loose electrical connections, has been faced in any installation, six of which have completed more than one year of operation.

The overall efficiency of the systems measured in the field indicated the significance of design pumping head. As most of the systems are installed at off-design pumping head conditions (less than half the design head) due to difficulty in identifying technically ideal site, the system efficiencies are low as compared to theoretical calculated ones. Measurements conducted at simulated pumping head equal to the designed one for the Gual Pahari system showed an increase in overall efficiency of the system. The table presents overall system efficiencies measured at different sites.

Site	Total Pumping Head (m)	Efficiency (%)
Golaghati, Tripura	6	0.82
Zirpitanda, Maharashtra	7	0.81
Gual Pahari, Haryana	9*	1.11
Gual Pahari, Haryana	20*	2.00
Indrapura, Rajasthan	12	1.36
Sikkabamin, Arunachal Pradesh	12	1.30
Tilonia, Rajasthan	20**	1.06
Theoretical (calculated under field conditions)	20	3.50

* Simulated

** Designed for 50 m head

Social Aspects

The PV system which has been provided as a replacement to existing handpump in most installations, has been found reliable by users. Communities belonging to site where distribution network including storage tank, pipes and taps was not completed or even initiated during the time of

survey, felt very strongly that the optimum utilisation of the system was linked closely with the effective distribution sub-system.

The system has been found viable for Indian conditions from technical performance point-of-view, though it was felt that the execution of the project could have been more effective if the introduction of the technology was integrated with the end-use scheme alongwith the renewable energy scheme.

The need for an exhaustive and update data base at least at district level on drinking water requirements and ground water details of the entire regions is an essential requirement for planning any similar projects, particularly for identifying technically compatible sites to an already designed system. This data base can be effectively kept by the agency responsible for executing drinking water supply scheme. The routine O&M requirements as also the security and safety of the system, can then be looked after at district, block or even at panchayat level, planned and co-ordinated with the help of the local body associated with rural water supply scheme. The specific maintenance requirements which need the technically skilled manpower and required spare parts, can be taken care of by the nodal renewable energy agency.

1.0 Photovoltaic Pumping for Rural Water Supply

1.1 Pumping needs and conventional technologies for rural water supply

Human consumption (drinking and cooking), irrigation and cattle consumption (drinking) are three basic needs of a rural community which water has to satisfy irrespective of its origin. While the available quality and quantity of surface water e.g. ponds, streams, lakes etc. may suffice for irrigation and cattle consumption, hygienically clean water is a minimum necessity for the health and well-being of the human population. Ground water has been the safest and most reliable amongst traditional sources of clean potable water. Conventionally followed water pumping techniques for rural water supply (drinking and domestic applications) belong to three main groups (1):

- * Use of mechanical energy provided by man power in conjunction with equipments e.g. simple rope and bucket, handle or wheel with goatskin bottle, hand-pump, foot-pumps etc.
- * use of animal energy to turn flush-wheels made of wood or metal, and
- * use of diesel engine or electric motor driven pumps.

The human energy output for water pumping depends on the age and strength of the user, the working hours and ambient conditions. Although very little information is available on the quantum of human energy available for work such as pumping water, it may be estimated to be equivalent to a power output of 50-75 W, at a comfortable level over a

prolonged period (2). The quantum may be translated to an energy output of 0.4 to 0.6 kWh in 8 hours. The energy would be sufficient to pump approximately 8-12 m³ of water from a depth of 10 m, using a pump with a mechanical energy efficiency of 50%.

The average energy output of a drought animal is five to ten times greater than that of a man. An animal of 500 kg body weight can lift 25-50 m³ of water over a head of 10 m in 8 to 10 hours using a suitable pumping device having an efficiency of 20% (2). Since the animals are mostly owned by individuals, the animal power is not so commonly used for community drinking water supply.

Low speed diesel engines are commonly used for small scale pumping systems. The overall conversion efficiency of the diesel driven pumping system is about 10-15%, which is often found lower in the field depending on the level of maintenance of the engine. Diesel engines require considerable maintenance and their lifetime is limited. Also, their power output is relatively high for small community water supplies as engines below 3 kW rated power output are not available.

Electricity from the mains grid is also used for water pumping. However, it is viable only if reliable power supply is available from the mains grid which is not distant from the source of the water. Although the overall conversion efficiency of the device, called 'wire-to-water' efficiency

is about 30-40%, they are not very attractive for community water supply due to frequent interruptions in the power supply and fluctuations in supply voltage.

These inherent constraints associated with conventional rural water supply technologies have increased the use of renewable energy technologies for pumping water significantly over the past few years. Hydropower, solar energy, wind and biomass fuels have since been used in some cases. Each of these technologies offer certain advantages over the other. However, their viability and availability are linked to many parameters specific to the location which may or may not be under the control of the planner or designer.

In order to promote the development of reliable and low-maintenance water supply technologies, the United Nations in 1980 launched the 'International Drinking Water Supply and Sanitation Decade (1981-1990) with the goal to provide safe drinking water and sanitation to all rural and urban population (3). Consequently, United Nations, World Bank and various U.S. Government agencies sponsored a study to investigate the comparative viability of hand pumps, solar photovoltaics and diesel pumping technologies. In addition, the United Nations Development Programme (UNDP) and World Bank sponsored a world-wide programme to demonstrate and evaluate solar pumping systems, both Photovoltaic (PV) and thermal (4). The study which included field trials, laboratory testing and economic analysis, resulted in the development of PV pumping system for wide-scale applications

(5). The technology is now being used for rural water supply applications in many developing countries. In India, the Department of Non-conventional Energy Sources, in association with the Technology Mission on Drinking Water, is promoting the use of solar photovoltaics for supplying water for drinking and domestic applications to remote communities.

1.2 The technology

Photovoltaic technology traces back its origin to 1839 when PV effect was discovered by the French Scientist Becquerel. In 1958, the technology was used for the first time in providing power to space satellite, Vanguard-I launched by the U.S.A.

The fundamental power unit of a PV system is a solar cell which is a semiconductor device designed to convert sunlight into electricity. The process involves direct conversion of energy and does not include any moving parts. Several solar cells are connected together to form a string, and are then laminated into a module to increase the power output. Lamination also provides a protective cover for otherwise breakable solar cells. A complete PV system has an array of suitably connected modules, power conditioning equipment and the required load with or without provision for energy storage.

Photovoltaic technology has certain inherent characteristics which make it suitable for use in various applications:

- * PV systems have no fuel requirement other than naturally available solar energy
- * They are modular, composed of individual PV modules, such that each system can be sized to meet a particular demand
- * Expected life time of a PV module is approximately 15-20 years
- * Routine O&M requirements are minimal
- * Pollution and noise free operation.

All over the world, PV systems have found applications in several fields including lighting, pumping, refrigeration, telecommunication etc. Several studies conducted world-wide have shown that PV pumping systems have successfully been used both for drinking water supply as well as irrigation purposes (6, 7). The relative merits of PV pumping systems as compared to various other technologies have been highlighted in such studies (8). These are presented in table 1.1.

Table 1.1 Comparison of pumping technologies

Technology	Advantages	Disadvantages
Hand Pumps	<ul style="list-style-type: none"> o local manufacture is possible o easy to maintain o low capital cost o no fuel costs 	<ul style="list-style-type: none"> o loss of human productivity o often an inefficient use of boreholes o only low flow rates are achievable
Animal driven pumps	<ul style="list-style-type: none"> o more powerful than humans o lower wages than human power o dung may be used for cooking fuel 	<ul style="list-style-type: none"> o animals require feeding all year round
Hydraulic pumps (e.g. rams)	<ul style="list-style-type: none"> o unattended operation o easy to maintain o low cost o long life o high reliability 	<ul style="list-style-type: none"> o require specific site conditions o low output o high capital cost in some cases

Wind pumps	o unattended operation o easy maintenance o long life	o water storage is required for low wind periods o high system design and project planning needs o difficult to install
Solar PV	o unattended operation o low maintenance o easy installation o long life	o high capital costs o water storage is required for cloudy periods o repairs require skilled technicians
Diesel and Gasoline pumps	o quick and easy to install o low capital costs o widely used o can be portable	o fuel supplies erratic and expensive o high maintenance costs o short life expectancy o noise and fume pollution

Source: Ref. (8)

1.3 Development and current status

1.3.1 System configurations

There are many kinds of PV pumping systems which are available commercially in the market. Five configurations are commonly used (4, 8). These are :

- (i) Submerged multistage centrifugal motor pumpset
- (ii) Submerged pump with surface mounted motor
- (iii) Reciprocating positive displacement pump
- (iv) Floating motor pump set
- (v) Surface suction pumpsets.

Each of these configurations are presented in Fig. 1.1, a, b, c, d and e respectively. Characteristics of each of the five configurations are discussed in table 1.2 along with the names of their suppliers. No single configuration is ideally suited for the entire range of applications.

Annexure 1A gives specific information on a few available commercial products.

Table 1.2: PV pumping system configuration and their suppliers

Configuration	Characteristics/shortcomings	suppliers
Submerged multistage centrifugal motor pumpset	<ul style="list-style-type: none"> o either A.C. or D.C. motor can be incorporated into the pumpset o easy to install often with lay flat flexible pipe work o equipment need to be pulled from the well for maintenance of D.C. motor used o inverter needed for A.C. system 	<ul style="list-style-type: none"> o AEG, W. Germany o BP Solar Systems - U.K. o Grundfos International A/s - Denmark o Italsolar - Italy o Siemens Solar GmbH - W. Germany o Total Energie - France o CEL - India o KSB pumps - India.
Submerged pump with surface mounted motor (turbine pumps)	<ul style="list-style-type: none"> o easy access to the motors for maintenance o power losses in shaft bearings and high cost of installation 	<ul style="list-style-type: none"> o Mono Pumps Ltd. Australia
Reciprocating positive displacement pump (Jack pump)	<ul style="list-style-type: none"> o very suitable for high head, low flow applications o output is proportional to speed of the pump o power controller for impedance matching often required 	<ul style="list-style-type: none"> o ERGO industries inc. Canada
Floating motor pump-set	<ul style="list-style-type: none"> o ideal for pumping from canal and open wells o pumpset is portable and negligible chances of it running dry o most common type utilize D.C. motor 	<ul style="list-style-type: none"> o BP solar systems U.K. o Solar electric international - Malta o Total eneric - France
Surface suction pump set	<ul style="list-style-type: none"> o not recommended unless presence of operator ensured o self start and pumping problems experienced o impractical to have suction heads of more than 8 m 	<ul style="list-style-type: none"> o DINH company Inc., U.S.A. o A.Y. Macdonald Manufacturing U.S.A.

Source: Ref. (8).

1.3.2 Field programmes

Several available studies have shown that PV pumping systems have been successfully deployed all over the world

(4, 9, 10). Figure 1.2 gives an estimate of total installations cumulative up to 1988 (10). Accordingly, 6000 systems had been installed all over the world by the end of the year 1988. Table 1.3 gives an idea of the variation in the type of organizations which have purchased PV pumping systems from Grundfos International, Denmark since 1982 and the variation in applications (11).

Table 1.3: Supply of systems by Grundfos International

Country	Purchaser	Nature of application
Australia	Farmer	Stock watering
Algeria	Minister of New Energy	Village water
Bangladesh	AEC	Irrigation
Benin	Rotary club	Monastery water
Botswana	MMRWA	--
Ethiopia	Swedish church aid	--
India	DNES	
Kenya	Denish aid programme	--
Mali	Ministry of interior Aqua viva	--
Somalia	Danish church aid	--
Sudan	Norwegian church aid	--
U.S.A.	Private parties	--
Zaire	Swedish church organisation	--
Zimbabwe	Rotary international	--

Source : Ref. (11)

One of the world's largest PV pumping systems, Zambelli plant in Verona, Italy, has been supplying drinking water since 1985 to a village reservoir located 350 m above plant level (12). The plant incorporates following features:

- * 70 kW_p installed capacity, 40 V design voltage
- * no battery storage, load being connected to the PV array directly
- * two variable frequency PWM inverters powering two AC driven piston pumps (35 kW each, 350 m head)
- * maximum power tracking capability.
- * stand-alone operation
- * completely automated system for plant control and monitoring.

During the course of its operation, the automatic control and monitoring system has been changed to increase the reliability of the control and data monitoring.

The PV pumping programme is likely to receive a boost with European community aid programme which perhaps is the largest in the history of PV. The project includes supply/installation of 1,040 PV pumping systems to Sahil countries in Africa. Following categories of systems would be utilised for the programme:

- | | |
|---|-------------|
| 1. Surface pumps of 300-350 watts | - 41 units |
| 2. Surface pumps of 600-650 watts | - 196 units |
| 3. Submersible pumps of 600-650 watts | - 233 units |
| 4. Submersible pumps of 1350-1450 watts | - 368 units |

- | | | |
|---|---|-----------|
| 5. Submersible pumps of 2300-2500 watts | - | 136 units |
| 6. Submersible pumps of 3700-3900 watts | - | 76 units |

The project is expected to finish by the end of 1991 (13).

1.4 Indian programme

In 1984, a special project was initiated to demonstrate and popularize the use of PV pumping systems under the National Solar Photovoltaic Energy Demonstration (NASPED) Programme. The project covered the states of Andhra Pradesh, Bihar, Orissa, Tamil Nadu, U.P. and West Bengal (14). It was decided to supply 100 pumping systems at nominal prices to individual farmers through nodal agencies. The most commonly used configuration consisted of 300/360 W_p PV array, a manual tracking system and a matching DC motor pump set (15). The programme was co-ordinated by the Department of Non-conventional Energy Sources (DNES). Since then, DNES has been co-ordinating the PV pumping system programme in India in association with various National and State level organizations.

In 1986, the DNES sponsored two studies on the evaluation of performance and impact of individually managed water pumping systems in various states. These studies were commissioned by the Administrative Staff College of India, Hyderabad and National Productivity Council (16). During the same year, the department also supported studies to develop deep well pumping system for larger capacity and to evaluate imported systems (17).

Central Electronics Ltd. (CEL) and Bharat Heavy Electricals Ltd. (BHEL), both in the public sector are the major suppliers of PV pumping systems in India. These systems are also supplied by Rajasthan Electronics and Instrument Ltd. (REIL). Recently, KSB pumps ltd., a well known pump manufacturer has also entered the PV pumping market.

Figure 1.3 presents the target figure for the supply of PV pumping system by the DNES for each financial year. The figure also compares the actual systems supplied till December of that financial year.

The DNES is currently participating in the activities of national Drinking Water Mission which is being implemented by the Department of Rural Development. Till December 1989, 20 deep well PV pumping systems have been supplied under this project (18).

As a part of DNES activities towards evaluating imported PV pumping systems, Tata Energy Research Institute has installed and evaluated PV pumping systems manufactured in France and donated to India by the French author Mr. Dominique Lapierre. This report discusses the implementation and the results of this project.

1.5 About the project

1.5.1 Background

The French organization 'Centre National De La Recherche Scientifique (CNRS)' under its programme ASVIN,

Application Solaires dans in Villages de l 'Inde et der Nepal
had installed two PV pumping systems in India. The first system was installed in 1981 in Sarwal, a tribal village in Ranchi district of Bihar. Second one was installed in Gopalpur in Keonjhar district of Orissa in the year 1986. The main objective of the ASVIN programme with reference to PV pumping system project was to develop a very poor tribal, remote, unelectrified village having no rains other than monsoon and very low agricultural output. The basic statement of the programme is 'ground water does not belong to anybody and the ownership of the land should not be the criteria to divide the benefits of PV pumping' (19, 20) With this objective, the first village Sarwal was selected and a PV pumping system using DC turbine pump was installed. The pumped water was mainly used for irrigation purposes which was not an earlier practice in the village.

In order to expand the project to nearby villages, ten more PV pumping systems were donated to India in 1987 by the author Mr. Dominique Lapierre out of the royalty of his book entitled 'City of Joy'. To quote Mr. Lapierre

It is a donation from an individual to a community of people struggling with surviving, with the hope to help them remain on their land instead of leaving for the horrors of Calcutta slums.

(Personal communication, May 1988)

Government of India, in a kind gesture, granted a total tax exemption for this donation, and the Department of Non-conventional Energy Sources sponsored the project. Tata

Energy Research Institute undertook the responsibilities of co-ordination and implementation of this project. The project work was initiated in October 1988.

1.5.2 Objectives

Objective as defined and followed by ASVIN programme was to develop the village socio-economically, aiming at the development of man, taking technology only a means of achievement (20). The approach, therefore, was to utilize the already available PV pumping system to achieve the development of a needy community.

While appreciating the objectives of ASVIN programme and acknowledging the benefits offered by the system to the community, TERI conceived the project from the view of implementation of a new technology in the field and finding conditions/situations under which the benefit from the technology could be maximized.

The system specifications provided by the supplier of these systems indicated that on a clear sunny day, the system designed for pumping water from a total pumping head of 20 m is expected to give 70 m³ of water. While the one designed for 50 m head is expected to give 18 m³ water per day. The irrigation requirements as per the FAO document "Crop Water Requirements", are estimated to be 50 m³/day/hectare for vegetables, 100 m³/day/hectare for rice and 50 litres per day per person for drinking and other domestic water requirements

(21). The systems under study would thus have been suitable for irrigating only one hectare of vegetable field (assuming the actual water output is less than the supplier's specified output of 70 m^3 per day). In addition, since these systems were meant for community applications, they could not have been given to an individual for irrigating his private farm. Community irrigation, though feasible with such systems, would have involved a detailed development programme and other infrastructural requirements which would have been of the dimensions of an independent project at the level of each chosen community. The most feasible application of these systems appeared to be for rural water supply for a community of approximately 1000 individuals.

Hence, the objectives clearly defined by TERI were:

- * to select sites facing problem of reliable rural water supply, in addition to being technically compatible with the pumping systems
- * to install and commission all the systems at selected sites
- * to study their field performance and impact on the user community

1.5.3 Scope

Scope of the work and activities associated with each objective are presented in Table 1.4. Details are provided in subsequent sections.

Table 1.4: Project objectives and associated activities

Objective	Scope
1. to select suitable sites	1.1 formation of the steering committee 1.2 identification of prospective areas/ regions/states where system could be installed 1.3 identification and selection of nodal agencies in the selected regions 1.4 site selection
2. to install and commission all the systems at selected sites	2.1 installation of first system at Gual Pahari to gain field experience 2.2 organizing a training programme for the representatives of user agencies 2.3 supervision during installation and commissioning
3. to study their field performance and impact on user community	3.1 collection of daily water output data from Gual Pahari system 3.2 conducting experiments on Gual Pahari system to know the overall efficiency and system performance at simulated pumping heads 3.3 one week monitoring trips to all other systems for studying their performance 3.4 analysis and writing of final report

2.0 Site Selection and Installation

It is important that the available conditions at each site conform to the technical specifications of the pumping system in order to ensure optimum performance. Therefore, close matching between the parameters of the two is preferable. In addition, the proposed site should also offer potential in terms of chosen applications.

Selection of suitable sites and subsequent installation of pumping systems at each selected site, therefore, formed the major activities in the project.

The subsequent sections enumerate the criteria that were considered while selecting sites for these pumping systems, the actual installation process and experiences during the installation phase.

2.1 Site selection

The site selection was done in three phases in which several aspects of the pumping systems were considered in detail. Amongst the preliminary information procured were water requirement, well yield, climatic factors, usage pattern, total pumping head, etc. The final selection of sites was done only after field visits. Discussed below is the detailed procedure followed during the various phases of site selection.

2.1.1. Phase I: Identification of regions and nodal agencies

2.1.1.1 Constitution of the Steering Committee

The Steering Committee was conceived as the main guiding force for accelerating the process of decision making during the site selection process and for subsequent effective execution of the project. The role of the Steering Committee included reviewing the work done periodically with a view to clear any bottlenecks in the field work.

The following members were nominated on the Steering Committee:

1.	Dr. J. Gururaja	Advisor, DNES	Chairman
2.	Dr. R.K. Pachauri	Director, TERI	Member
3.	Dr. T.K. Bhattacharya	Consultant, TERI	Member
4.	Dr. B.M.S. Bist	P.S.O., DNES	Member
5.	Ms. Akanksha Chaurey	Research Associate TERI	Member

2.1.1.2 Identification of regions for installation

Most of the Indian subcontinent lies in the tropical and temperate zones and therefore sunshine is abundant in most parts. Regions for installation of Solar Photovoltaic Water Pumping Systems can be identified on the basis of following factors:

- (a) ground water availability and water level depth
- (b) sunshine hours and availability of solar radiation.

It was decided to install the systems all over the country to enable comparison of system performance and utilisation in different regions. Therefore, it was attempted

to choose representative states from the five broad regions of India. Table 2.1 describes the same.

Table 2.1 Selected states for PV pump installation in India

Region	Selected state	Remarks
Northern	Haryana	TERI has a good infrastructure in Haryana; Easier for detailed study due to proximity to Delhi.
	Rajasthan	Scarcity of water and electricity
Western	Gujarat	Scarcity of water, Nodal agency has required infrastructure
	Maharashtra	Hot and dry climate resulting in water scarcity.
Central	Madhya Pradesh	Hot and dry climate resulting in water scarcity; unelectrified sites abundant.
Southern	Karnataka	Hot and dry climates.
Eastern	Bihar	Drought prone areas.
&	Orissa	Dry, economically backward areas
North-Eastern	Arunachal	Good scope for PV pumps for drinking water supply and an enthusiastic Government Deptt.
	Tripura	Good scope for PV water pumps, and an enthusiastic Government Department.

2.1.1.3 Identification of nodal agencies

Nodal agencies active in selected regions were identified to collaborate in this project with respect to assuming local O&M responsibilities for the system. Since these agencies would be familiar with the local terrain and have their own infrastructural facilities, they could play an important supportive role in the project. A training

workshop was organised to familiarise the personnel from these agencies with the project objectives and the pumping system installation and operation. A list of the agencies chosen for this study has been compiled in table 2.2. A brief introduction of each of these follows thereafter

Table 2.2: Selected nodal agencies for coordinating the project at local level

Sl No.	Selected State	Agency	Location	Type	Remarks
1.	Haryana	TERI	7 Jor Bagh, New Delhi	Research	Owned land in Haryana. Programme implementer.
2.	Rajasthan	Social Works Research Centre	Tilonia Distt. Ajmer, Rajasthan	Voluntary	Suggested by CNRS, France; doing good work in rural development. Possesses required infrastructure
3.	Rajasthan	Rajasthan Energy Development Agency	Jaipur, Rajasthan	State Level	Co-ordinating most of the renewables related activities in the state.
4.	Gujarat	Gujarat Energy Development Agency	Vadodara, Gujarat	State Level	The agency is well known for its energy development activities.
5.	Maharashtra	Maharashtra Energy Development Agency	Bombay, Maharashtra	State Level	The agency has good infra-structural network in Maharashtra.
6.	Madhya Pradesh	MP Urja Vikas Nigam	Bhopal, Madhya Pradesh	State Level	The agency co-ordinates most of the energy related activities in the State.
7.	Karnataka	MYRADA	Bangalore, Karnataka	Voluntary	The agency has a commendable track record of completing several development projects in the rural areas successfully.
8.	Karnataka	Karnataka Electricity Board	Bangalore, Karnataka	State Level	The KEB has taken several steps to promote renewable technologies.
9.	Karnataka	Karnataka State Council for Sci. & Technology	Bangalore, Karnataka	State Level (autonomous)	The Council had a wide experience and the necessary infrastructure to undertake such projects.

10. Bihar	Society for Rural Industrialization	Ranchi, Bihar	Voluntary	The Agency has been involved in the work of training rural manpower in various technologies. It was also recommended by CNRS, France.
11. Orissa	Minor Irrigation Deptt.	Keonjhar, Orissa	State Level	The Department has been actively engaged in installation of PV operated devices for the last few years. It was recommended by CNRS, France.
12. Arunachal Pradesh	Rural Works Department	Itanagar, Arunachal Pradesh	State Level	Being a remote state without access to thermal power, PV technologies have been given emphasis by the RWD.
13. Tripura	Dept. of Science, Technology and Environment	Agartala, Tripura	State Level	The Department has been implementing renewable energy based programmes for the past several years in the State. Even large scale PV power plants had been installed.

1. **Social Works & Research Centre (SWRC) Tilonia:** It is an organization active in the field of providing drinking water, promoting local handicraft and women welfare. Located in a small place Tilonia in Distt. Ajmer, the organization is currently developing a technology centre with various units including a communication centre, library, museum, open air theatre, conference facilities etc. The members of SWRC Tilonia are very familiar with renewable energy systems.

2. **Rajasthan Energy Development Agency (REDA), Jaipur:** It is a state level organization working in close association with the DNES and other local organizations. REDA has been responsible for most of the renewable energy projects in the state of Rajasthan. It has installed several PV pumping

systems in various places in Rajasthan. It also has an experience in dealing with several other PV devices.

3. Gujarat Energy Development Agency (GEDA), Vadodara: GEDA is one of the earliest organisations in India to take up work on renewable energy. With its headquarters in Vadodara the organisation has been involved in the introduction of several PV operated systems, solar thermal energy based systems and wind generators in the state of Gujarat.

4. Maharashtra Energy Development Agency (MEDA), Bombay: The Maharashtra Energy Development Agency has been sponsoring and coordinating most of the activities related to renewable energy in the state of Maharashtra. The agency has installed several devices like PV domestic lights, pumping systems, colour TVs, telecommunication systems, power plants, wind generators, improved cook stoves, etc. Though Maharashtra is a fully electrified state, there are several remote areas where decentralized energy options are viable and MEDA is responsible for their implementation.

5. Madhya Pradesh Urja Vikas Nigam Limited (MPUVNL), Bhopal: The agency is involved in most of the renewable energy related issues in the state of Madhya Pradesh (M.P.). Since M.P. is ideally suited for PV technologies, the MPUVN was chosen in the state for participating in the project with TERI.

6. MYRADA, Bangalore: The voluntary organisation headquartered in Bangalore is committed towards upliftment of

the rural masses. The primary activities of the organisation include training of rural manpower in the skills of modern agriculture, animal husbandry and food processing. They also aim at making the rural population aware of the need for energy conservation and the available renewable energy options.

7. Karnataka Electricity Board (KEB), Bangalore: The KEB is the main body responsible for generation and distribution of electrical power in Karnataka. A distinguishing feature of the board, however, is that it has taken keen interest in the promotion and dissemination of renewable technologies, especially solar photovoltaics. The board has installed several PV operated lighting systems in various parts of Karnataka.

8. Karnataka State Council for Science & Technology (KSCST), Bangalore: The KSCST is playing a pivotal role in the promotion of renewable technologies in Karnataka. It has been associated with field trials of several technologies such as improved cookstoves, PV lighting systems and pumping systems, wind pumps and biomass gasifiers. The council has a dedicated technical staff, a good infrastructural facility and sufficient skilled manpower.

9. Society for Rural Industrialization (SRI) Ranchi: The tribal belt of Ranchi constitutes the area of operation of this organisation. The primary objective of SRI is to equip the rural youth with technical skills and knowledge so as to

enable them to find suitable avenues of self-employment within the rural setting and thus halt the exodus to the cities. The SRI has also been lately diversifying into renewable technologies and has been able to develop considerable awareness amongst the population. The SRI has a large campus with all requisite workshop facilities. It also enjoys a good reputation amongst the villagers. The SRI had been recommended by the CNRS, France.

10. Minor Irrigation Division (MID) Keonjhar: The department is involved in the construction of small and medium sized dams and canal irrigation systems in the state of Orissa. Since the early eighties it has been involved with the ASVIN programme in which the organisation has installed a PV pumping system at village Gopalpur in Keonjhar district. The department has also installed PV lights in their sheds and buildings. CNRS, France recommended this organisation.

11. Rural Works Department (RWD) Itanagar: The department undertakes all the work pertaining to rural areas from road construction to drilling of borewells or rural water supply schemes in the state of Arunachal Pradesh. A major portion of this state consists of difficult terrain and remotely located villages, many of which are inaccessible. No thermal power plant is located here due to unavailability of coal - most of the grid electricity is supplied through diesel generating plants. In view of this, the RWD, which is a subsidiary of the Government of Arunachal Pradesh, is taking up the task of promotion of decentralized renewable technology options.

12. Department of Science, Technology & Environment (DSTE), Agartala: Promotion of renewable technologies is being taken up in Tripura by this department. The organisation has installed number of PV pumping systems, in addition to several other devices such as PV street lights and colour televisions. The DSTE is also overseeing the work in the areas of science, technologies and environment in the state of Tripura.

2.1.2 Phase 2: Development of site selection criteria and shortlisting of sites

The second phase of the project consisted of the following activities:

- Correspondence with all the selected agencies to communicate the objectives of the project and specifications for proposing suitable sites.
- Organisation of a training workshop for the representatives from each selected agency.
- Discussions on the comparative merits and demerits of the proposed sites during the training workshop, and
- Finalising of site selection criteria based on the discussions during the workshop and planning for field visits for site selection.

2.1.2.1 Correspondence with selected agencies

After selection of the nodal agencies, letters were sent to them seeking their participation in the implementation of the project. The agencies were informed of the technical specifications of the pumping systems and the

details of site requirements and were asked to propose suitable sites for the same. The site details were to be obtained as per the proforma in annexure 2A developed jointly by DNES and TERI. The agencies were also communicated about the training programme and requested to depute one or two of their personnel for this training workshop. KEB and KQCST were contacted after MYRADA withdrew from the project, which occurred after the workshop was held. The response from various agencies towards the correspondence is summarised in table 2.3.

Table 2.3: Responses of local agencies

Agency	Response	Participation in training workshop
SWRC Tilonia Rajasthan	favourable	Yes
REDA, Rajasthan	favourable	Yes
GEDA, Gujarat	"	Yes
MEDA, Maharashtra	"	Yes
MPUVNL, M.P.	No response	No
MYRADA, Karnataka	Initially favourable but declined later	No
SRI, Bihar	Late	No
MID, Orissa	No	No
RWD Arunachal Pradesh	favourable	Yes
DSTE, Tripura	"	No

2.1.2.2 Organisation of training workshop

Before initiating the site selection, it was necessary for the project team to be completely familiar with the PV

pumping system under study, its subsystems and components. It was therefore decided to install one of the systems at the TERI campus in Haryana in order to gain insight into the kind and amount of work required for installation, as also its operation under actual field conditions. The pumped water was planned to be provided to saplings planted on the adjoining land as part of a forestry project. Accordingly the system was installed and commissioned on October 26, 1988. System specifications are described in section 3.0.

It was thought essential for the staff of the local agencies to be conversant with the detailed installation procedure even though TERI was to supervise the installation. A two-day workshop was conducted on 21st and 22nd December, 1988 in Delhi for the representatives of the nodal agencies. The objectives of the programme were:

- * to discuss all the proposed sites individually in an open session.
- * to familiarise the co-ordinators of the project at local level with the pumping system and to acquaint them with step-by-step installation procedure.
- * to finalise field visits and dispatch procedures for the system to their respective sites.

Although it was communicated to all the agencies that attending the workshop was mandatory, only five sent their representatives (Table 2.3).

The main activities during the workshop included sessions on the following:

1. Introduction to PV pumping systems.
2. Siting and end use management considerations for PV systems, and
3. Practical session on installation procedure at Gual Pahari site.

Training material prepared for session 1 and system particulars provided by the manufacturers, introduced during session 3 have been given in annexures 2B and 2C respectively. During session 3, the participants were taken to the TERI campus at Gual Pahari, district Gurgaon, Haryana where the entire installation procedure including foundation construction, plumbing jobs, panel assembly, wiring, pump installation etc. were demonstrated. The participants installed the system to familiarise themselves with the entire procedure. The discussions ensuing during course of session 2 on siting have been elaborated in the next section.

2.1.2.3 Discussion on sites proposed by participating agencies

During the session on siting and end use management, the respective participants from the participating agencies were made to give individual presentations describing their sites and the reasons for choosing them. The session provided a very good forum for exchange of views and comparison between local conditions in selected regions.

Arunachal Pradesh: Mr. V.N. Pandey participated in the workshop on behalf of RWD and presented a brief description of his area which is summarised below.

The proposed site was in Pasighat area of East Siang district which is in the foothills, the water table in this area being approximately 10 m. The system was mainly to be used for drinking water supply. Each village in Arunachal Pradesh has about 30-40 households with more than one family comprising a household. People in this area have shortage of water. Due to sociological aspects and local habits, wastage of water is more in Arunachal Pradesh and hence water requirements are more. The system under study was proposed to be installed on the community land but the exact location was not yet decided. The RWD accepted to undertake the tasks of constructing the storage and distribution system for water.

It appeared that although Itanagar and Pasighat have PV systems installed on experimental basis by the organisation the public awareness was required to be created as people are superstitious. However, PV lighting systems seem to have created a favourable impact on the community. Electricity availability is a regular problem in the area due to absence of any thermal power plant in the vicinity and the PV electricity is treated as god-gifted.

Comments: End-use and distribution, particularly that of waste-water, were to be developed properly.

2. Gujarat: Mr. S.J. Palva represented (GEDA). The proposed site, a tribal village, was Ruppura near Palanpur in Sabarkantha distt. having a distance of about 250 km from Vadodara. The human population of the village was approximately 573 and cattlehead count was about 444. Water table depth was reported to be about of 18 m in summer and 15 m in winter.

PV pumped water was proposed to be used for drinking and for minor irrigation for vegetable etc. Originally, drinking water was being provided from two wells and 6 hand pumps. It was also proposed that the PV pumping system would be installed on Panchayat land and storage tank will be constructed for water required by cattle and for washing purposes.

Comments: As there appears to be no drinking water problem in this village, nor has minor irrigation been done till now, it was recommended that a few more sites should be considered.

3. Maharashtra: Mr. Shrikant Ashtikar from Zilla Parishad, Jalna attended the workshop on behalf of MEDA.

Village Man Deolgaon in Distt. Jalna was proposed by MEDA for the installation of the pump. The human population of the village was 1400 while the cattle population was approximately 300. Water depth in this area was reported to be between 5-13 m. The village was said to be near a geological duke. The total water requirement was estimated

to be about 100 m^3 per day by the Zilla Parishad. About 60-70 m^3 water per day was already available (electric pumps were used to fill up the existing storage tank). The PV pump was proposed to supply remaining 30 m^3 of water required per day.

The land to be used for installation belonged to the government and was allotted to village panchayat. Village panchayat had accepted to look after the system. The distribution system was to be the same as the old one, and the water was proposed to be provided through community taps. Indoor taps could be optional. No hinderance from shadows of trees or buildings was reported at the proposed location for the array.

Comments: It was felt that the system will not be optimally used because water requirement was not much. In addition the water table was much lower than the pump is designed for. In consultation with MEDA and Zilla Parishad, Jalna, a better alternative site could be considered.

4. Tilonia, Rajasthan: One 50 m pump was earmarked for installation in Rajasthan with the help of Social Works and Research Centre, Tilonia. Mr. Bhagwat Nandan and Mr. Swaran Singh participated in the workshop.

SWRC proposed Nangal village in Jaipur distt. for the installation of one pump. The village had about 700 families and the total cattle population of 3500. The water available

in this area was reported to be salty and therefore the existing hand pumps were also not used. There was only one sweet water well in which water was available at shallow depth. At larger depths, the water becomes salty. It appeared that the availability of drinking water was so scarce that villagers were buying one pitcher of water for Rs. 15/- (the water was supplied from Sambar lake about 15 km away by tankers arranged by private agencies).

Another proposed site was Korsina village in Jaipur distt. which faced an acute water problem. There was an open well having potable water from which water was being pumped using an 8 HP diesel pump. This water was supplied to villages in Nagaur distt. Representatives of SWRC Tilonia proposed that the PV pump be installed in this particular well and water supplied to villagers in Korsina using gravity flow system.

Comments: The slope towards these villages from the well was to be checked up before a gravity flow system could be designed. Also, it was not advisable to put two pumps in one open well (a PV pumping system in addition to already installed 8 HP diesel pump). Therefore, an alternate site was to be chosen with the help of SWRC.

5. Rajasthan: Mr. S. Hajela represented REDA in the workshop.

The proposed site was situated in Tehsil Mandalgarh of Bhilwara district. The village is called Indrapura. The

approximate human population was stated to be 210 while number of cattlehead was 700. The village was unelectrified but PV lighting systems had been installed in this village. The water table depth in the village was reported to be 15-20 m as per the records of Public Health and Engineering Department (PHED).

Comments: The site was yet to be visited by REDA. The final selection could be made only after the site is visited.

2.1.2.4 Finalisation of site selection criteria on basis of feedback from the workshop

The following aspects were identified as critical while selecting a site for installation.

- * Need for an average 35-50 m³ water per day
- * Weather characteristics
- * Land selected for the installation should be community land
- * Details of the well including type (borewell or open well), yield and depth of water should be clearly and accurately stated.
- * Details of the location of the array, land and surroundings should be provided.
- * Details of water management should include the following:
 - (i) distance and slope of the point of utilisation of water from the system
 - (ii) proposed distribution network
 - (iii) storage
 - (iv) waste water utilisation

- * Social structure of the village and infrastructure available for instillation and maintenance of the system should be looked into.
- * Level of user participation in the local management of the project should be considered.

Proforma for collection of information on sites were developed based on these criteria and the participants were asked to use them for recording the collected information. Annexure 2D gives the proforma.

2.1.3 Phase 3: Finalisation of sites for installation of the PV pumping systems

The visits to specific regions were planned to obtain relevant information and data to select the best possible site. The forthcoming paragraphs discuss the experiences during the site selection visits to various regions. The data/information with respect to each site was collected in the proforma shown in Annexure 2D.

2.1.3.1 Bihar

During the visit to Ranchi in Bihar, four sites were considered for the installation to be done by SRI. The details have been summarised in table 2.4. In general, it was found that most sites in Ranchi would be unsuitable for these PV pumping systems because in most places the bedrock was within three feet of the ground level. The water table was very shallow and most of the rain water was wasted as sub-surface run-off. SRI was therefore asked to look for

more sites in collaboration with the donor agency and develop the project as per the ASVIN programme of CNRS France.

Table 2.4 Details of sites visited in Bihar

S.No.	Village Name	Block/ district	Accepted/ rejected	Remarks/Reasons for Selection/rejection
1	Theki	Lapung, Ranchi	R	Shallow water table depth, slow recharge, rocky/uneven terrace
2	SRI Campus	Ranchi	R	Shallow water table
3	Churchu	Churchu, Hazaribagh	R	Shallow water table depth
4	Hakkadoba	Khunti, Ranchi	R	Shallow water table depth, too many tall trees.

2.1.3.2. Orissa

The only site proposed for the PV pumping system in this district was village Upper Ridiah which was in the hills, west of Keonjhar city. The system was proposed to be located in a stream running in a small valley in order to irrigate the upper reaches. This is a difficult task to be done with the help of a submersible pump but since the minor irrigation department had the necessary infrastructure to cope with the situation, they were to be provided with one system at the behest of the donor. The agency has not kept in touch since then.

2.1.3.3 Karnataka

• The visit to Bangalore was planned in conjunction with MYRADA. All the sites proposed for the installation by MYRADA

were situated in Bangarpet block of Kolar district where the organisation has most of its infrastructure (Table 2.5). A common feature of most sites was that there was very little or no common land available and in several places water table depth was too deep. Finally the village Kanamana Halli was chosen which had suitable land for the system and close proximity to the user community. The system was however, not installed anywhere in this region because later on MYRADA withdrew from the project.

Table 2.5 Details of site visited in Karnataka.

S.No.	Village	Block district	Installation Accepted/ Rejected	Remarks
1.	Lakkana Halli	Bangerpet Kolar	R	Land was privates, village was located far away, low well yield.
2.	Kanamana Halli	-do-	R	Installation could not be done due to withdrawal of MYRADA from the project.
3.	Bodagurki	-do-	R	Site was shaded.
4.	Neriantha	-do-	R	Conventional water supply system was installed recently.
5.	Thamata Makala	-do-	R	-do-
6.	Yerngololu	-do-	R	-do-

During January 1990, another tour was undertaken to Karnataka, this time with a different local organisation, the KSCST. The site selection process was repeated and three

days were spent in visiting the areas of Daudballapur, Neelmangla and Hoskote. Finally the village Uparahalli of Hoskote block was shortlisted since as per local records, the boring was supposed to have a good yield.

The installation was completed as per the usual procedure. However, on commissioning the systems, very low discharge was observed. This was because the boring had collapsed inside. According to the geologist, it could not be repaired. Therefore, it was decided to shift the pump to another site.

The KSCST staff conducted another search for a suitable site and finally had it shifted to village Hosahalli (Teklahalli) in Daudballapur block.

2.1.3.4 Maharashtra

Initially the following 7 sites were proposed by the Zilla Parishad in Jalna.

- 1) Ramkheda, Tq. & Distt Jalna :- Village population is 313. Village has two borewells with handpumps. Each borewell (BW) has got the yield of 25000 lits/hr. Village is electrified. Water level in winter and summer ranges from 15 to 30 metres. Water table (30 m) would be unsuitable for system under study.
- 2) Sarwadi Ner Tq & Distt. Jalna :- Village population is 271. Village has two borewells with handpumps. One BW has yield of 3363 lits/hr. Village is electrified. Water level in winter and summer ranges from 15 to 25 metres. The BW yield is lower than required by PV system.

- 3) Tandulwadi Tq. & Distt. Jalna:- Village population is 381. Two BW with handpumps are already existing. One of the Borewell has yield 1500 lits/hr. village is electrified. Water level in winter and summer ranges from 20 to 30 metres. The BW yield is lower than required.
- 4) Ita No.1 Tq. Bhokardan Dist. Jalna:- Village population is 450. Three BW exist with handpumps installed. One BW is having yield of 3363 lit./hr. Village is electrified. Water level in BW in winter and summer ranges from 10 to 25 metres. Reflection of shadows of adjoining trees would pose a problem.
- 5) Sirasgaon Tq Parthur Distt. Jalna :- Village population is 737. Four BW with handpumps exist. One BW is having yield of 3363 lits/hr. Village is electrified. Water level in winter and summer ranges form 12 to 25 metres yield is found lower for PV systems.
- 6) Bhondewadi. Tq. Parthur Distt. Jalna :- Village population is 341. Two BW with handpumps exist. Village is electrified. Water level in winter & summer ranges from 10 to 20 metres. Solar array foundation very near to Borewell will not be possible due to nearby houses and internal village road. On BW is having yield of 52000 lits/hr.
- 7) Gebrai Tq. Parthur Dist. Jalna:- Village population is 760. Five borewells with handpumps exist. One BW is having yield of 52000 lits/Hr. Water level ranges from 15

to 25 metres. Village is electrified. No open space for array found.

In most of these villages, water table in summer was expected to go deeper than that suited for the PV system. Also, borewell yields were much lower. Therefore a few more sites were visited, details of which have been enumerated in table 2.6. One major obstacle to the installation of PV pumping systems in this area was that borewells were generally located in the midst of a cluster of huts or houses making it difficult to demarcate a piece of land for the array. Two sites marked with an asterisk in the table were tentatively shortlisted for installation.

Table 2.6 Details of sites visited in Jalna, Maharashtra

S. No.	Village	Block	District	Accepted/ Rejected	Remarks
1.	Sarvadi	Ner	Jalna	R	Pumpset water is not required because of nearby lake.
2.	Jaitpur	Jalna	Jalna	R	Shadow water depth, people uncooperative shadow problems.
3.	Dahiphal Tanda	Jalna	Jalna	A*	The yield of the well needed to be re-tested and confirmed.
4.	Pakhni	Parthur	Jalna	R	No land available for array.
5.	Palshi	Parthur	Jalna	R	Land insufficient, shade problems.
6.	Banachi-wadi	Parthur	Jalna	R	Land unsuitable for array
7.	Rajur-karkotha		Jalna	A*	Unelectrified

* Shortlisted

It was also decided to visit some other area particularly Nagpur district where the local officials were keen to install the PV pumping system. Accordingly, Nagpur was visited in the first week of March 1989 and proposed sites were seen alongwith officials of the Zilla Parishad (Table 2.7). The sites visited were situated in blocks Parshivni and Umrer. Of these, Parshivni block was totally unelectrified and was comprised of uneven topography. Village Dhawalpur in this block was found to be most suitable, except for well yield which was not clear from the GSDA (Ground Water Survey and Development Agency) records. Installation was not possible unless a yield test was conducted on the well. It was, therefore; decided to go through one more round of site selection in Maharashtra before installing the system for the chosen site.

Table 2.7 Details of sites in Nagpur, Maharashtra

S. No.	Village	Block	District	Accepted Rejected	Remarks
1.	Kolitmara	Parshivni	Nagpur	R	Land not suitable for array
2.	Dhawalpur & Saungi	Parshivni	Nagpur	A	Land suitable, no shade problems good topography for overhead tank but well yield not checked.
3.		Umrer	Nagpur	R	Well yield was less, water was salty.

2.1.3.5 Rajasthan (Tilonia)

The SWRC Tilonia has been using several renewable based devices for a long time. The main problem encountered while selecting sites in this area was the depth of water table from ground level which was more than 50 m. Also, the groundwater was mostly salty. Initially the village "Faluda" situated near Tilonia was visited for the installation. In this village, SWRC has a scheme of drinking water supply to individual households which has been worked out with a full co-operation and involvement from villagers. Except a couple of hand-pumps in the village provided by SWRC, there is no source of drinking water available. About 100 m away from the village, SWRC runs a school which has an open well inside its campus. With a mutual agreement, a diesel pump has been installed in this well and water supply is given to interested households through a well designed underground pipeline network. Since the villagers are required to pay a nominal amount, their interests are present in this scheme. SWRC has not faced any kind of management problems. The village, however was not considered due to excessive distance of the borewell site from the main village. The second option was to install the system in the campus of the SWRC itself and use it to meet the water requirements of the residential complex. This option was later finalised.

2.1.3.6 Gujarat

During field visits to Gujarat, three sites proposed by GEDA were visited. A religious organization having its

campus near Vadodara, required a pumping system to irrigate a 50 acre farm where fodder and fruits were grown for the temple community. One 7.5 HP pump was already irrigating the farm. An additional system was requested for use by about 100 swamis living in the temple complex and practicing various religious acts e.g. discourses, discussions, yagna ceremonies etc. The temple was also involved in social activities. The swamis organised youth festivals, cultural activities etc. and provided help during times of natural calamities. They were well educated some of them even having a science and technology background. After visiting the temple and farm and interacting with the swamis, it was felt very strongly that this organization is resourceful enough to manage on its own. There was no doubt a need for more water for irrigation, the site was technically suitable and the temple had sufficient infrastructure to maintain and monitor the pumping systems, still it was not justified to install the system at a place where enough resources were available to arrange for a conventional system.

The second organisation proposed by GEDA was social organization. Its activities included providing medical facilities, care for mentally retarded children, primary schooling etc. There were about 300 persons staying in the campus and another 400 were visiting the hospital everyday. Water for drinking was lifted manually from an openwell. The Ashram had a small farm being irrigated from a canal using wood gasifier pump.

The entire community of the ashram, would have been benefited if the system under study was installed in the existing well. However, the water table at 5 m was unsuitable for the PV system. The third campus visited belonged to a residential-cum-academic institution for rural youth interested in learning rural technologies. On visiting the site, it was found that there is already a wood gasifier pump installed in the borewell which supplies water for the entire requirement of the community. There is no actual need for PV pumping system in the campus. Considering these aspects, it was felt that none of the sites visited in Gujarat were suitable for PV systems installation.

2.1.3.7 Tripura

During the visit to Tripura in March, 1989, it was found that the DSTE had already selected a site which was situated at village Golaghati about 50 Km from Agartala. Since the boring was in the midst of a cluster of huts which could cast shadow on the array, the DSTE agreed to shift the huts to a new location. The installation was completed in the same trip since the system had reached Agartala.

2.1.3.8 Arunachal Pradesh

The first trip to Arunachal Pradesh, which was planned during April, 1989 had to be cancelled due to bad weather. Ultimately it was planned to complete the site selection and installation in a single trip in June 1989. During the site selection phase of this tour, three sites were visited. Details are given in Table 2.8. The village "Sikkabamin"

was finally chosen since it had a good location for the array in the midst of a clearing between the huts.

Table 2.8: Details of sites visited in Arunachal Pradesh

S.	Village	Block	District	Accepted- Rejected	Remarks
1.	Berun	Pasighat	Pasighat	R	Shadow problems
2.	Rani	Pasighat	Pasighat	R	Far away from village
3.	Sikkab- amin	Pasighat	Pasighat	A	Fairly open space, good co-operation from the people.

2.1.3.9 Rajasthan (REDA)

The first village was 'Indrapura' having a population of about 650 and was approachable through a kuchcha road only. There was only one handpump in the village provided by PHED, Rajasthan. A small water channel flowing next to the village which gets water from the seepage from Pachyanpura Dam nearby, provided water for all other purposes except drinking.

The entire civil work required for the installation including the construction of GLR and welded mesh fencing around the array was agreed to be taken care of by PHED on a special request from REDA.

The second village was 'Cheetavar' near the first village. It was a small village with the population of about 550, divided into two hamlets. One handpump each had been provided in these hamlets by PHED. A single handpump was

found to be sufficient for the drinking water need of one hamlet. Since the village is a gypsy village, their domestic water requirements were found to be very small.

It was felt after talking to the community that there is no additional water requirement, hence, no need to provide any more source of water.

Village 'Paparvar' was the third village visited (population 600). As there was no handpump or any other source of drinking water found in the village, drinking water was taken from a dirty well/pond using a diesel pump belonging to a farmer. There was no community facility for drinking water. The approach to the village was through the village Indrapura after crossing the water channel. A truck can easily pass through the channel.

REDA finally selected village Indrapura. TERI did not participate in the installation of the system at this site. Some administrative and social problems encountered with respect to the site selection and installation have been discussed in section 4.0. The installation at Indrapura was finally completed in December, 1989.

2.2 Installation and commissioning of the PV Pumping systems

The nature of installation varied for each site depending upon the local site conditions, available materials and the local agencies outlook. However, certain general

guidelines were developed for time-scheduling the procedure for installation of a system:

- Day : 1
 - demarcation of area for array
 - marking a East-West line in the demarcated area
 - digging of trench along this line
- Day : 2
 - grouting of array foundation and supports.
 - aligning of supports
 - assembly of panels
 - completion of plumping jobs (on motor-pump unit)
- Day : 3
 - wiring of panels, junction box and inverter
 - mounting of inverter cabinet
 - sinking of motor-pump unit
 - installation of panels on supports
 - completion of wiring
 - commissioning the system

The relevant details with respect to the PV pump installations at various sites has been compiled in table 2.9. A list of relevant materials required during the installation was sent before hand to each agency. The list is given in Annexure 2E. Figure 2. (a-g) present systems commissioned at given sites.

Table 2.9: Detailed information on various installations

Organization concerned	TERI	DSTE, Tripura	SWRC, Tilonia, Rajasthan
Contact person: Name and address	Ms. Akanksha Chaurey Tata Energy Research Institute 103, Jorbagh New Delhi - 110 003	Mr. T.K. Roy Dept. of Science, Tech. and Environment, Assam Rifles Complex Gorkhabasti, Kunjaban Agartala	Shri Bhagwat Mandan Sewada SWRC, Tilonia 305316 Madanganj, Dist. Ajmer, Rajasthan
Name of the village Block and district	Gual pahari, TERI campus Dist. Gurgaon Haryana	Golaghati, West Tripura district, Tripura	Technology Centre, SWRC Campus, Tilonia, Rajasthan
No. of households/ population	No residents in the campus except chowkidar	100 families	100 people (approx.)
Site electrified	Yes	Yes	No
Well type	Borewell	Borewell	Borewell
Water table	9 m	6 m	20 m
Month of commissioning	October 1988	March 1989	May 1989
Post installation work			
a) Fencing/boundary	Entire installation	Entire installation	Array has been installed on the roof top of a bldg.
b) Water tank	No	Not proposed	Existing: Capacity 20 m ³
c) Distribution system (brief details)	Direct supply using pipe	Direct collection by beneficiaries	Existing: underground pipelines to all the utilization points, taps have been provided
Utilization of water			
a) No. of people being benefited	50 people (drinking)	100 families	100 people (approx.)
b) Used for drinking	Yes	Yes	Yes
c) Used for irrigation	Yes	--	No
Performance			
a) any problem encountered	No	No	No
Specific comment		Chips and brick pieces were used in the absence of gravel	Mounting structure for the array has been constructed in SWRC, Array is installed on the roof of a building

Organization concerned	RWD, Arunachal Pradesh	MEDA, Maharashtra	REDA, Jaipur
Contact person: Name and Address	Mr. V.N. Pande, AE (Mech.) RWD, Sub division Along Along - 791001 Arunachal Pradesh	Mr. G.K. Bhide, MEDA 6th Floor, New Kamani Chambers, Adi Marzban St. Ballard Estate Bombay 400 038	Mr. S.J. Hajela Asst. executive REDA C-33, Lajpat Marg C-Scheme Jaipur 302 001
Name of the village block and	Sikkabasin, Pasighat region, Arunachal Pradesh	Zirpitanda, Block Ambad, Dist. Jalna, (Maharashtra)	Indrapura (census code 19/11/237) Tehsil Mandalgarh Dist. Bhilwara Rajasthan
No. of households/ population	88 households	Population - 900	650 population
Site electrified	Yes	No	No
Well type	Borewell	Borewell	Borewell
Water table	12 m	7 m	12 m
Month of commissioning	June 1989	November 1989	December 1989
Post installation work			
a) Fencing/boundary	Entire installation	Only array	Fencing of welded mesh
b) Water tank	Proposed	Proposed	constructed GLR of 50 m ³ capacity
c) Distribution system (brief details)	One pipeline & direct distribution	Proposed to supply pipes from tank to convenient spots in village	Pipe connec- tion with GLR and cattle water trough
Utilization of water			
a) No. of people being benefited	80 households	900	650 people
b) Used for drinking	Yes	Yes	Yes
c) Used for irrigation	No	No	No

Performance a) any problem encountered	Loose connections in the inverter probably caused by the transportation. Taken care of without such effort	No	Loose connections in the inverter probably caused by the transportation. It was taken care of without such effort.
Any other comment	Trench like foundation unlike pits constructed elsewhere	Five more sites visited. One selected and installation done	Installation done by REDA with the help of PHED

Organization concerned	KSCST
Contact person: Name and address	Mr. Saapath Kumar Systems Analyst, KSCST IISC Campus, Bangalore.
Name of the village Block and district	Teklahalli, Doddballapur, Bangalore (Rural)
No. of households/population	20 houses population 120
Site electrified	Yes
Well type	borewell
Water table Month of commissioning	10m (appx) May 1990
Post installation Work a) Fencing/boundary	
b) Water tank	Proposed
c) Distribution system (brief details)	A pipeline is to be designed
Utilisation of water	
a) No. of people being benefited	125
b) Used for drinking	Yes
c) Used for irrigation	Not Yet
Performance	
a) any problem encountered	No
Any other comment	KSCST is exploring possibilities of initiating sericulture, energy plantation, fisheries and private irrigation as a consequence of installation of the system.

3.0 Performance Evaluation

Essentially, the PV pumping system consists of following four sub-systems which are the following:

- (i) PV array to convert solar irradiance into direct current (DC) electricity.
- (ii) Control equipment; in this case being the inverter which converts DC into alternating current (AC) electricity to power 3-phase AC motor.
- (iii) Motor-pump assembly to convert electricity into mechanical power for pumping water.
- (iv) Water storage and distribution system.

The input solar energy to the array undergoes several conversions before it is made available as mechanical energy for pumping water. Each conversion has associated energy losses which ultimately influence the cost of pumping water. The efficiencies with which energy is converted and distributed are of major importance. Figure 3.1 illustrates the energy flow in a PV pumping system.

The general relationship between solar irradiance, power supply from the array and the hydraulic power output is shown in fig. 3.2. The output from the array varies as the irradiance on the array plane changes. The efficiency of the motor/pump unit is affected by the current and voltage from the array which in turn, is reflected in the water output pattern.

Briefly, a typical day's operation of PV pumping system is described as follows. The system starts pumping water when the irradiance rises above a certain threshold level. The water output rate continues to increase with the irradiance. As the motor/pump unit reaches its optimal operating point, the overall system efficiency improves and the rate of water output rises more rapidly than does the irradiance. In the afternoon, when the ambient temperature and thus the solar cell operating temperature increase, the efficiency of PV conversion decreases. Although, the PV electrical output increases later in the afternoon as the array cools down, water output continues to reduce on account of low irradiance. Finally, the system stops pumping water when the irradiance is below the threshold and the array is unable to generate sufficient electrical power (5).

Following sections discuss the operating characteristics of each of the sub-systems.

3.1 Sub-systems and their operating characteristics

3.1.1 Photovoltaic modular array

PV array is the power generator of the system. The power output capacity of a PV module is rated in peak watts (W_p). This is the value of the power output from a module operating at its maximum power point, under 1000 W/m^2 solar irradiance and at a cell operating temperature of 25°C . The modules in an array are electrically connected together so that the current and voltage produced by all of them add up to give a total array current and voltage. The current-

voltage characteristics of a PV module at different irradiance levels and array temperatures are shown in fig. 3.3.

As seen from fig. 3.3, the solar cell's voltage varies very little with the light intensity, while the current is directly proportional to it (22). Also, at constant light intensity, a rise in cell temperature produces a proportional decrease in voltage. Solar cell current remains relatively steady despite changing temperatures. As the PV power is the product of voltage and current, it decreases as the cell temperature increases (23). Under typical field conditions, the cell operating temperature would be a few tens of $^{\circ}\text{C}$ higher than the ambient temperature. The relation is defined as per the equation below (24):

$$T_c(^{\circ}\text{C}) = T_a(^{\circ}\text{C}) + 0.3 \times \text{intensity (mW/cm}^2) \quad \dots (3.1)$$

The instantaneous array efficiency or array power, which is a linear function of cell temperature $T_c(^{\circ}\text{C})$, is

$$\eta_c = \eta_R [1 - \beta (T_c - T_R)] \quad \dots (3.2)$$

Where the reference array efficiency η_R is the product of the cell packing factor and the cell reference efficiency determined at a reference cell temperature T_R . β is the temperature coefficient of efficiency and it is relatively constant over a range of temperatures encountered in terrestrial flat plate arrays. The typical value of β is between 0.35% and $0.4\% \text{ }^{\circ}\text{C}^{-1}$ (24, 25).

An important feature of the PV output characteristics is that the output from PV device not only depends on the light intensity and cell temperature, but also on the point on I-V curve at which it is operated. The maximum power from a PV device is obtained when it is operated at a point occurring at the knee of the I-V curve. This point is known as Maximum Power Point (fig. 3.3). While designing a PV power system, it should be ensured that the load operating point coincides with the maximum power point of the array I-V curves at all irradiances and cell temperatures. Alternately, an array would perform optimally if it is always loaded at its maximum power point.

3.1.2 Inverter

Inverter is the device, circuit or system used to deliver AC power when energized from a source of DC power. In the PV pumping system, it converts DC power from the PV array into AC power and feeds it to the 3-phase AC motor of the motor/pump unit.

Current inverter technology utilizes solid state devices such as transistors and thyristors. Inverters having AC output frequencies in the range of 50-60 Hz are generally saturable-core oscillator type. At full load, the efficiency is in the vicinity of 75 percent and the output voltage is about 106 V (26).

In saturable-core oscillator type inverters, the output AC waveform is a square wave which is unique in that its

peak, average and effective values are all equal to each other. In most practical situations, the frequency of the generated waveform is directly proportional to the DC supply voltage. It is independent of transistor parameters and temperature. The frequency stability of saturable-core inverter can be made quite good.

The inherent property of saturable-core inverter is utilized in operation of pumping system at lower irradiance level. As the array voltage rises initially, the frequency of AC power also increases, thus increasing the rpm of the motor, enabling the pump to give water output even at low irradiance level.

3.1.3 Motor/pump unit

The advantages offered by submerged multistage centrifugal motor pumpset have already been highlighted in section 1.3. The use of an inverter becomes inevitable with an AC motor. The most common type of AC motors used for several applications including prime movers for water pumps, are squirrel cage induction type motors. For a fairly large change in the mechanical load applied to them, the rpm of the motor changes only by a small percentage, provided that the frequency of the AC supplied to the motor remains constant. Changing the frequency changes the synchronous speed. The large variations in the voltage would however, affect the speed and torque of AC motors (27, 28).

The advantages of centrifugal pumps are simplicity, low maintenance and availability of design for a range of flow rates and pumping heads. A centrifugal pump consists of a set of rotating vanes, called impeller, enclosed within a stationary housing called casing. Water is forced into the center of the impeller by atmospheric pressure due to suction by the impeller and imparted a rotation by the impeller vanes. The resulting centrifugal force accelerates the fluid outward between the vanes until it is thrown from the periphery of the impeller into the casing. The casing collects the liquid, converts a portion of its velocity energy into pressure energy, and directs the fluid out of the pump outlet. Fig 3.4 shows a simple centrifugal pump (29).

3.1.3.1 Performance parameters

Capacity, Head, Power, Efficiency, Required Net Positive Suction Head and Specific Speed are parameters that describe a pump's performance (30).

(i) Capacity (Q):

Volume of water per unit time delivered by the pump. In SI units, Q is usually expressed in litres per minute (l/min) or cubic meters per second (m^3/s).

(ii) Head (H):

Net work done on a unit weight of water by the pump. It is given by

$$H = \left[\frac{P}{\tau} + \frac{v^2}{2g} + Z \right]_{\text{discharge}} - \left[\frac{P}{\tau} + \frac{v^2}{2g} + Z \right]_{\text{suction}}$$

P = Water pressure (kPa)

γ = Specific weight of fluid/water (kN/m^3)

V = Velocity of fluid/water (m/s)

g = Acceleration due to gravity (9.81 m/s^2)

Z = Elevation head above a datum (m). For vertical pumps datum is a horizontal plane through the entrance eye of the first-stage impeller.

(iii) Power (W):

Power imparted to the water by the pump.

$$W \text{ (kW)} = \frac{QH}{K}$$

K = Unit constt ($K = 6116$ for Q in l/min and 0.102 for Q in m^3/s)

(iv) Required Net Positive Suction Head (NPSH)_r :

Amount of energy required to prevent the formation of vapor-filled cavities of fluid within the eye of single and first-stage impellers.

(v) Specific Speed (N_S):

An index to pump performance, derived using dimensional analysis.

$$N_S \text{ (rpm)} = \frac{NQ^{1/2}}{H}$$

N = Pump speed (rpm)

3.1.3.2 Performance characteristics

Curves relating pump capacity to head, efficiency, power and required net positive suction head are utilized to

describe operating properties of a pump. Characteristic curves of a pump is the set of these four curves. Figure 3.5 describes characteristics curve of centrifugal pump at various speeds (29). It is important to note that at any fixed speed, the pump will operate at combinations of head and capacity given by its H-Q curve at that particular speed.

The particular H-Q combination at which the pump is operating is its operating point. The operating point will change with the head, and in this process both the brake horsepower and efficiency will change even if the speed at the pump is held constant. The efficiency of a centrifugal pump steadily increases to a peak and then declines as Q increases from zero. There is generally only one specified efficiency curve for a particular impeller.

Efficiency is also related to the types of materials used in construction, the finish on casings, the quality of machining and the type and quality of bearings used.

The optimum range of operation of a centrifugal pump at any given speed is indicated in the fig. 3.6 by isoefficiency lines. The efficiency would decrease considerably both at very high head (very low discharge) and very low head (very high discharge).

3.2 Matching motor/pump and array power output characteristics

To start operation, the motor/pump subsystem requires a certain power to overcome the starting torque. A centrifugal

pump has a relatively low starting torque and will readily start to rotate slowly even if the irradiance is low. There would not be any water output until irradiance has increased to a level where array power is sufficient to develop the rotational speed required for pumping. The level of irradiance is the threshold level.

Maximum power point tracking or the fixed voltage operation are two possible mechanisms by which PV power output is maximized. In other words the power to the motor is controlled so that the power produced at lower irradiance levels can be maximized to start the operation of the pump.

Inverters are commonly equipped with fixed-voltage inputs or maximum power point tracker to provide impedance matching. The voltage and frequency of output AC current are automatically increased by the inverter at low irradiance levels to enable the pumping system to deliver water (2).

3.3 Specifications of the system used

The system under study includes four main elements:

1. PV modules
2. DC-to-AC inverter
3. Submersible electric motor-pump unit.
4. Other hardware, such as metal frames for panels and array, wires, cables, etc.

3.3.1 PV modules

Thirty two (32) modules, manufactured by Photowatt, France, each having a capacity of 40 W_p at STC, have been

used in the system. A single module has thirty six (36) multicrystalline solar cells connected in series. Four (4) such modules are series connected and fixed using metal frames to form a panel. These panels (eight in number) are interconnected and fixed on the channels to form the array. The total array capacity is 1,280 W_p when measured under Standard Test Conditions (STC). Figure 3.7 shows single module and its characteristics as per the supplier. Module dimensions are 1042 x 462 x 46 mm.

3.3.2 DC-to-AC inverter

DC-to-AC inverter has been specially designed by Total Energie, France for pumping "following the sun". It transforms direct current from the PV array to variable frequency alternating current. This frequency is related to the insolation. Figure 3.8 shows a sketch of the inverter. Its main characteristics are;

Input voltage	: 100 to 120 V
Output voltage	: 80 V to 60 Hz
Frequency	: 0 to 60 Hz
Safety Features	: Protection provided against polarity inversion, and overload or short circuit at the output.

Inverter also protects the pump by stopping it in case the water level in the borehole becomes too low.

3.3.3 Submersible Motor-pump Unit

It is a 4" submersible multistage centrifugal pump with a three phase AC maintenance-free motor. Nine pumping units have been designed to operate at their maximum efficiency when the total pumping head is 20 ± 1 m. while one has been designed for 50 ± 1 m. The units have been manufactured by Leroy Somer, France. Figures 3.9, 3.10 and 3.11 give the motor, the pump and pump characteristics for RA series used in the system. The rated parameters specified on the unit are 67V, 50 HZ, 8.8A, $\cos \phi = 0.84$, kW/ch = 0.6 and rpm 2820.

3.4 Methods of evaluation

The basic step in assessing the performance of PV pumping system is to relate its water output to the available solar energy on the array, i.e., the overall field energy conversion efficiency of the system. In addition, sub-system efficiencies could be calculated by monitoring energy input and output to individual components of the system. The system output can also be predicted for certain reference site conditions with the help of field collected data.

Three different approaches were followed to evaluate the performance of commissioned systems. These methods were developed according to the resources available on each site. They were:

1. Record of daily water output data
2. (a) Measurement of overall system efficiency for all installations.

(b) Measurements of sub-system efficiencies for Gual-Pahari installation.

3. Studying the performance at simulated pumping heads using data collected from Gual-Pahari system.

3.4.1 Approach 1 : daily output

Each nodal organization was asked to depute one person to keep a record of daily water output from the system. The organizations were asked to procure two inch diameter vane type water meter which was installed on the delivery pipeline to facilitate recording of data. Record sheets to collect daily water output data were developed based on recommended format as described in references (5) and (22) and distributed to all nodal organizations. The field staff was instructed to record the water meter reading on each evening after the pumping system had stopped pumping water. Annexure 3A presents the format of record sheet. Record of solar irradiance data could not be kept due to unavailability of recording instruments at each site. Table 3.1 gives the expected output from each system as specified by the supplier.

Table 3.1: Expected water output under $6 \text{ kWh/m}^2/\text{day}$

T.M.H. (m)	Daily output (m ³)
20	70
50	18

3.4.2. Approach 2(a) : Overall system energy conversion efficiency

Overall system energy conversion efficiency is defined as the ratio of hydraulic energy output to the solar energy received by the array during a fixed duration. It can be calculated as (31, 32):

$$\eta_s = \frac{\rho v g H}{GA} \quad \text{or} \quad \frac{\rho g Q H}{EA}$$

ρ = density of water (kg/m^3)

v = volume of pumped water (m^3)

g = acceleration due to gravity (9.81 m/s^2)

H = total pumping head (m)

Q = flow rate or capacity (m^3/s)

E = Solar irradiance on the plane of array (W/m^2)

G = Solar irradiation on the plane of array (Whr/m^2)

A = Total module area (m^2)

3.4.2.1 Protocol

To calculate the instantaneous overall system energy conversion efficiency of all commissioned systems, the required experiments were conducted at each site by TERI team. The team carried its own instrumentation required to study the technical performance of each system (details of instrumentation is provided in annexure 3B). Experiments were conducted for 4 to 5 days in continuation on each site.

Before initiating the experiment on each day, the array electrical output was measured to ensure functioning of all modules and electrical connections. Data was recorded as

per the standard format developed by TERI. A sample of data sheet is provided in annexure 3C. The following procedure was followed to conduct experiments.

* Each experiment for a duration of 2-3 hours consisting of the following simultaneous measurements.

- (i) Global solar irradiance on the plane of the array after an interval of every five minutes.
- (ii) Water meter reading after every ten minutes.
- (iii) Ambient temperature measurements at the beginning of the experiment and after every one hour subsequently.
- (iv) Total pumping head at the beginning of each experiment.

* Four to five such sets of experiments for each site.

* One hour data from each day's experiment representing a nearly constant solar irradiance level, used for efficiency calculations.

3.4.3 Approach 2(b): Sub-system efficiency

1. PV array: The PV array efficiency is defined as the ratio of array power output (or PV electrical energy output) to the solar irradiance (or solar irradiation) on the array plane

$$\eta_{PV} = \frac{VI}{EA}$$

V = array voltage (V)

I = array current (I)

2. Inverter: Efficiency of the inverter is the ratio of AC power output from the inverter to the DC power input (array power output)

$$\eta_{inv} = \frac{P_{AC}}{VI}$$

P_{AC} = AC power from the inverter

3. **Motor/pump unit:** The combined efficiency of motor/pump unit is the ratio of hydraulic power output to the input power which is the inverter output power.

$$\eta_{m/p} = \frac{P_{gQH}}{P_{AC}}$$

Overall system efficiency η_s is then a product of all three sub-systems efficiencies, viz., η_{PV} , η_{inv} , $\eta_{m/p}$.

3.4.3.1 Protocol

The measurements were done only at Gual Pahari system. As there was no infrastructure available to install any automatic data recording instrument, experiments were done manually.

Following two different procedures were followed:

- (i) determine the array power and efficiency, combined inverter and motor/pump unit efficiency, and flow rate variation with respect to solar irradiance on the plane of the array,
- (ii) individual sub-system efficiencies.

The first set of experiments incorporated simultaneous measurements with a frequency of one minute of the following parameters:

- (i) Solar irradiance level on the plane of the array
- (ii) Array voltage and current
- (iii) Water meter reading.

The experiments were conducted during afternoon with irradiance level falling upto the cut-off value when water output became zero.

The second set of experiments were done for a shorter duration of 15-30 minutes. Solar irradiation received, array electrical energy output, inverter AC energy output and total volume of water pumped were measured for a fixed duration of time.

Instrumentation is described in annexure 3B.

3.4.4 Approach 3: Performance at different simulated pumping heads

The minimum water output expected under design conditions could be estimated by doing field tests under simulated pumping head. The experiment done at different pumping heads could also indicate the significance of design pumping head and sub-optimal performance at off-design conditions.

3.4.4.1 Protocol

A precalibrated pressure gauge, suitable for a minimum Total Pumping Head specified and a gate valve were installed on the delivery pipe line to simulate various Total Pumping Heads. Experiments were done for a total duration of one hour on clear sunny days. Experimental procedure is described below:

- * Specified value of Total Pumping Head was simulated using pressure gauge and gate valve arrangements.

- * Solar irradiance was measured on the plane of the array at an interval of five minutes for a total duration of one hour. The values were then plotted against elapsed time and area under the curve was calculated, the value of which was designated as G_{rec} .
- * Initial and final readings of the water meter for one hour experiment giving the net water output during the elapsed time, W_{rec} .
- * Initial and final readings of ambient temperature, the average value was then used to estimate T_{cell} as per the expression 3.2 Intensity is taken as the average value of solar irradiance during the experiment, provided extreme values did not vary significantly.

3.5 Results and discussion

3.5.1 Daily water output

Table 3.2 summarizes the available record of daily water output data for all seven commissioned systems.

Table 3.2: Record of daily output data

Site	Nodal organisation	Month of commissioning	Deputed person/deptt. for collecting data	Data available	Remarks
Gual Pahari, Haryana	TERI	October 1988	Field staff TERI campus	Monthly average from December 1988 to January 1991	Computed from daily discharge
Golaghati, Tripura	DSTE	March 1989	DSTE staff	Daily discharge from 19th June to 18th august 1989	Data collected using crude method. Water meter installed only in April 1990. No data available since then.

Tilonia, Rajasthan	SWRC	May 1989	Drinking water division, SWRC	Daily discharge for October, November, December 1989, January-August 1990	Pump is operated as and when required. No information on total hours of operation daily
Sikkabasin, Arunachal Pradesh	RWD	June 1989	Office of Assistant Engineer RWD, Passighat	Daily discharge data for January August, 1989 collected using crude method & for Nov, Dec 1990 after inst- alling water meter	Data for Nov and Dec 1990 26.2 m ³ and 11.1 m ³ respectively.
Zirpitanda, Maharashtra	MEDA	November 1989	Zilla Parishad, Jalna	Daily discharge for November, December 1989 and January 90	Daily average 50 m ³
Indrapura, Rajasthan	REDA	December 1989	Office of Assistant Engineer PHED, Mandalgarh	Daily discharge for January, 1990 average 9 m ³	Water output less than expected due to wrong electrical connections of motor/pump unit to inverter.
Taklahalli, Karnataka	KSCST	May 1990	Staff of zilla Parishad	Daily discharge July 1990 August 1990 September 1990 October 1990 November 1990 December 1990 January 1991	18 m ³ 11.1 13.6 28.9 24.7 28.1 32.0 32.6

In the absence of any field collected data on daily mean global irradiation, ambient temperature and mean hours of sunshine for Gual Pahari, the statistical data from Indian Meteorological Department for New Delhi has been used for analysis. The distance between New Delhi station (data collecting station) and Gual Pahari is approximately 35 km. The data is reproduced in table 3.3

Table 3.3 : Solar radiation data for New Delhi

Month	Mean daily global solar radiation (kWh/m ² /day) (horizontal)	Mean daily global solar radiation on array tilted local latitude	Mean daily hours of sunshine (hrs)	Maximum air temperature (°C)
January	4.06	5.93	7.7	21.3
February	5.07	6.65	8.7	23.6
March	5.398	6.298	8.0	30.2
April	6.499	6.45	8.8	36.2
May	5.612	5.118	8.3	40.5
June	5.323	5.182	6.1	39.9
July	5.610	5.066	5.7	35.3
August	5.525	5.26	6.0	33.7
September	5.579	5.897	7.3	34.1
October	5.483	6.815	9.1	33.1
November	4.708	6.808	9.2	28.7
December	3.95	6.036	8.0	23.4

Source: Solar radiation over India by Anna Mani and S. Rangarajan, Published by Allied Publishers Pvt. Ltd.

Figure 3.12 gives mean daily discharge averaged over a month from December 1988 to January 1991 for Gual Pahari system.

The highest output obtained so far is 53.1 m³ (mean daily average over a month) in the month of April 1989. The value is only 76 per cent of the expected output at 6 kWh/m²/day as per the manufacturers specifications (Table 3.1).

As per the manufacturer's survey capacity diagram at $5 \text{ kWh/m}^2/\text{day}$ of irradiation given in fig. 3.13, none of the RA series pump is capable of giving an output of more than $20 \text{ m}^3/\text{day}$ at a head of 20 m. The observation was highlighted in a written correspondence with the manufacturer before any system was commissioned. No satisfactory clarification was given on this aspect.

Further, on comparing the expected output from these systems with other similar systems available, the figure for Photowatt systems appear higher. The information taken from literature presented in annexure 1A on Grundfos and Italsolar systems is presented here for comparison:

- * Grundfos system with 1.4 kW_p capacity array expected to pump 70 m^3 of water daily from a head of 20 m on an 11 hours standard solar day with an irradiation at $8,150 \text{ kWh/m}^2/\text{day}$.
- * With 1.12 kW_p capacity array, expected to pump 50 m^3 of water daily from a head of 20 m on the same reference day.
- * Italsolar system with 1.4 kW_p capacity array expected to pump 45 m^3 of water daily from a head of 20 m on a standard solar day with an irradiation at $6 \text{ kWh/m}^2/\text{day}$.

From the characteristic curves and data given in fig. 3.11, at 2900 rpm, the pump type RA5 is capable of pumping water at the rate of $6.8 \text{ m}^3/\text{h}$ at 10 m head and $4.55 \text{ m}^3/\text{h}$ at 20 m head. Since the rpm of the pump and the solar irradiation values have not been co-related for the system,

it is difficult to justify the manufacturers specified. Output of $70 \text{ m}^3/\text{day}$ on a reference day of $6 \text{ kWh/m}^2/\text{day}$ at 20 m head. Expected water output based on the sub-system efficiencies on the field is calculated in section 3.5.2.

The performance of Gual Pahari system however, matches well with the solar radiation data in table 3.3. The two consecutive years performance indicates the reliability of the system's performance. The system continues to pump water even at low insolation value of 155 W/m^2 on the plane of the array. The system stops pumping water although the pump continues to rotate after the insolation level falls further.

3.5.2 Overall system conversion efficiency and sub-system efficiencies

Overall efficiencies (instantaneous) of systems commissioned at Gual Pahari (Haryana), Indrapura (Rajasthan), Golaghati (Tripura), Zirpitanda (Maharashtra) and Tilonia (SWRC, Rajasthan) and Sikkabamin (Arunachal Pradesh) are given against total pumping head in Table 3.4. Systems commissioned at Sikkabamin, (Arunachal Pradesh) and Taklihalli, (Karnataka) could not be evaluated as there was no water meter installed at Sikkabamin while weather was unfavourable at Taklihalli during the respective visits to these sites. A preliminary measurements using stop watch has however, been made at Sikkabamin.

Table 3.4 : Overall system efficiency (instantaneous)

Site	Total pumping head (m)		Overall system efficiency (per cent)
	Designed	Actual	
Gual Pahari (TERI)	20	9	1.11
Indrapura (REDA)	20	12	1.36
Golaghati (DSTE, Tripura)	20	6	0.82
Zirpitanda (MEDA)	20	7	0.81
Tilonia (SWRC, Ajmer)	50	20	1.06
Sikkabamin (RWD, Arunachal Pradesh)	20	12	1.3

Figure 3.14 presents array efficiency vs. irradiation on the plane of the array. Module Fill Factor (FF) calculated under 930 W/m^2 irradiance on the plane of the array and 20.5°C ambient temperature is 0.65. The module packing factor is 0.9. The module is 8.3% efficient at STC as per the manufacturer. The array open circuit voltage and short circuit current measured under 1023 W/m^2 irradiance and 28°C air temperature are 145 V and 10 A respectively.

Sub-system efficiencies calculated as per the section 3.4.3 are described in table 3.5:

Table 3.5 : Calculated sub-system efficiencies

Sub-system/system	Efficiency (per cent)
PV array (η_{pv})	6.02
Inverter (η_{inv})	90
Motor/pump unit ($\eta_{m/p}$)	21.1
Overall ($\eta_s = \eta_{pv} \eta_{inv} \eta_{m/p}$)	1.14
Field conditions:	
Ambient temperature	: 29°C
Average solar irradiance during the experiment on the plane of the array	: 833 W/m ²
Total pumping head	: 9 m

From the typical data at 1000 W/m², AM 1.5 insolation supplied by the manufacturer on PV modules used in the system, the temperature coefficient θ has a value of 0.38% per °C for junction temperature rise of 35°C (Fig. 3.7).

The PV array which is rated for 1.28 kW_p at 1000 W/m², AM 1.5 insolation and 25°C cell operating temperature, would produce a total power equal to 1.14 kW_p at 833 W/m² on the array plane and an ambient temperature of 29°C as calculated using expressions 3.1 and 3.2.

The array efficiency under 833 W/m² on array plane and 29°C ambient temperature should be 8.9%* value which is almost 1.5 times the actual efficiency obtained in the field. The power output corresponding to NOCT (Nominal Operating

* The PV array area in these calculations through out the analysis has been taken as the total module area (product of module area and total number of modules in the array), without considering the array packing factor.

Cell Temperature is measured at an average clear day insolation of 800 W/m^2 , fixed ambient temperature of 20°C and wind speed of 1 m/s would be 1.19 kW_p and array efficiency would be 9.7% .

There are several considerations that can limit the power output of an array in the field, some of these are degradation, soiling of the array due to dirt accumulation and variance from the array's maximum power point. The rate at which the performance of a module decreases, is difficult to predict. The quality of module design, components other than solar cells used in a module, the temperature extremes that a module is exposed to and the effect of solar spectrum on the cover glass and solar cells are factors that cause module to degrade. It is estimated that PV energy output will decrease at a rate of about 1% to 2% a year due to all such factors (23).

Similarly, dirt accumulation on the PV module surface can also have an appreciable effect on its output power. In dense urban area, the high carbon content of urban pollution is considered the major cause of soiling. In the rural agricultural area, the pollen dust are the causes. The soiling factor, which is measured in terms of power generated despite soiling, could be anywhere between 3% to 8% after a six month exposure (23).

These factors could account for low conversion efficiency of the PV array at Gual Pahari as most of the

measurements were done one year after the system was commissioned. The site at Gual Pahari is an open agricultural area having frequent dust-storms. Although the modules are regularly cleaned with dry cloth, no detergent has been used to clean the surfaces.

In addition, the load which is powered by the PV array may cause the array to operate at a point different than its maximum power point. In Gual Pahari system, although the total pumping head is different from the designed head, the inverter is supposed to function as the maximum power point tracker, as per the manufacturer's claim. In the absence of any technical specifications available from the manufacturer on the inverter characteristics, it is difficult to compare the designed efficiency with that of the field obtained one. However, the 90 per cent efficiency obtained in the field is comparable to expected efficiency of modern technology inverters*.

The combined efficiency of motor pump unit as measured in the field is 21.1 per cent. The highest efficiency of the pump type RA 5 is 55% obtained at a flow rate between 3.3 and 4.2 m³/h (fig. 3.11). The flow rate corresponds to a total pumping head of 20 to 25 m (fig. 3.11). The induction motor

* Commercially available inverters from Photoelectric Inc. San Diego, U.S.A. and Heart Interface, Washington, rated at 3000 W and 1800 W respectively suitable to connect a PV array to 120/240 V, 60 Hz system, offer efficiencies in the range of 92 to 95 per cent. The high efficiency DC/AC inverter used in Grundfos pumping systems claims an efficiency of 95%. It is a variable frequency inverter incorporating constant voltage tracking.

used in the system usually has an efficiency in the range of 75-80 per cent. The combined highest efficiency of the unit (assuming 80% efficient motor and 55% efficient pump at designed head) is expected to be 44%.

The obtained 21.1% efficiency of motor/pump unit indicates the significance of designed pumping head. The unit is designed for 20 m head while it is actually working at a total pumping head of 9 m which has not changed much since the system was commissioned in October 1988 (8.7-9.4m). Total pumping head of 9 m corresponds to a flow rate higher than $6 \text{ m}^3/\text{h}$ at which the pump efficiency falls below 30% (fig. 3.11). The flow rate of $6 \text{ m}^3/\text{h}$ was also confirmed from the measurements done. Although the motor efficiency could not be measured independently, it was estimated from the combined unit efficiency of 21.1% and pump efficiency of 30% at actual pumping head of 9 m. The estimated motor efficiency was 70%.

From the characteristic curve of the pump, it is clear that the pump can operate at an optimum efficiency within a very small range of flow rate. It, therefore, becomes important that the desired flow rate be maintained to achieve the optimum performance of the entire motor/pump unit.

One way of controlling the flow rate of the pump is by changing the total pumping head. Experiments were done to simulate the total pumping head close to the desired pumping head with the help of pressure gauge and gate valve on the delivery pipe line. Results are discussed in section 3.5.2.2

3.5.2.1 Expected water output based on sub-system efficiencies

The overall expected system efficiency in the field conditions (833 W/m^2 irradiance and 29°C ambient temperature) at designed head would be 3.5 per cent which is a product of the following:

$$\eta_{\text{pv}} = 8.9\%$$

$$\eta_{\text{inv}} = 90\%$$

$$\eta_{\text{m/p}} = 44\%$$

The expected water output on the manufacturers chosen reference day of $6 \text{ kWh/m}^2/\text{d}$ would then be $59.4 \text{ m}^3/\text{d}$. It is possible to predict the average daily water output from Gual Pahari system for any month using subsystem efficiencies measured in the field. The estimated value can then be compared with actual water output received from the system. The average solar radiation received on the plane of the array for any particular month has been taken from table 3.3 in the absence of field collected data for the same. Table 3.6 presents the estimated and actual daily average water output from Gual Pahari system. The overall system efficiency used in these calculations has been calculated from the measured sub-system efficiencies ($\eta_{\text{pv}} = 6.02\%$, $\eta_{\text{inv}} = 90\%$, $\eta_{\text{m/p}} = 21.1\%$).

Table 3.6 : Estimated and Received Daily Water Output from Gual Pahari System

Month	Estimated daily water output	Received daily water output in 1990 (m ³)
January	40.9	37
February	46	21.8
March	43.52	43.4
April	44.57	47.3
May	35.36	40.6
June	35.81	38.7
July	35	32.9
August	36.34	36
September	40.75	34.8
October	47.09	45
November	47.04	41.3
December	41.71	37.4

Except for the month of February, the actual received water output figures compare well with the expected ones for the entire year. The daily average for the month of February in 1989, however, was 39.6 m³, a value closer to the expected one.

In these calculations, the overall system efficiency has been taken to be constant through out, though it may not be the case. The array efficiency varies with the level of insolation, the ambient temperature and the load. Similarly, the motor-pump unit efficiency is also susceptible to varying load conditions. Although, the load through out the year

remains fairly constant, variations in overall system efficiency are expected due to other factors.

3.5.3 Performance at simulated pumping head

Out of the 7 commissioned systems, 6 are designed for lifting water from a total pumping head of 20 m while one is designed for 50 m. However, none of the systems are installed at their designed pumping heads, resulting in much lower efficiencies than the optimum achievable for all the pumps.

To observe the performance of these systems at their designed operating conditions, experiments were conducted at Gual Pahari system (designed for 20 m, operating at 9 m) at different pumping heads simulated with the help of a pressure gauge and gate-valve. The experimental procedure has been described in section 3.4.4. Results are presented in table 3.7.

Table 3.7 : Performance at simulated pumping heads

Total simulated head pumping	Flow rate (m ³ /h)	η_{pump} (from Fig 3.11)	η_s
12	5.2	45%	1.6%
14	5.95	30%	1.6%
16	5.62	40%	1.7%
18	5.14	47%	1.7%
20	3.76	55%	2%

These results clearly show that the pump would work at its maximum designed efficiency of 55% only when it is installed at a total pumping head of 20 m.

The flow rate and thus the water output at 20 m pumping head is the least of all cases considered although the pump is working at its highest efficiency. The overall system efficiency is also highest in this case.

The Gual Pahari system (and all other systems) which is installed at 9 m head, is under utilised and it is possible that some excess power is available from the array.

As a follow up of the results, overall system efficiency was calculated at reduced array size. One parallel string of eight series connected modules was disconnected from the array consisting of four such strings. The array voltage did not change much but the current was reduced by 25%, reducing the array power to 3/4 of its original value. Further, one more string was disconnected and overall efficiency was calculated. Results are presented in table 3.8.

Table 3.8 : Performance at reduced array power

Array power (average)	Irradiance (average)	η_{PV} (per cent)	Flow ₃ rate (m ³ /h)	η_s (per cent)
917.73 W _p (110.45 V 8.309 A)	875.625 W/m ²	6.8	6.1	1.11
708.18 W _p (109.626 V 6.46 A)	902.125 W/m ²	6.8	5.3	1.25
470.59 W _p (108.43 V 4.34 A)	920.56 W/m ²	6.6	4.1	1.41

Total Pump Head : 9 m Ambient Temp = 20°C

The array efficiency obtained during the experiment is the highest achieved in the field at Gual Pahari. High level of solar irradiance and low ambient temperature are accountable for higher array efficiency.

Although the overall efficiency of the system shows an increasing trend with reducing array power, indicating an excess power is available from the array at Gual Pahari, the excess power may not be available at all times of the day or during all seasons.

One critical design aspect of PV systems is that they are optimally designed, keeping into account the seasonal, daily and often the hourly variations in solar related parameters. The PV pumping system is designed such that water is available for maximum hours of sunshine during the day. It is possible that excess PV power is available during certain hours of the day, reduced PV array power may not be adequate to pump water at hours of low irradiance level.

Second aspect worth considering is matching of various sub-system parameters. Even though the total pumping load at Gual Pahari is 50 per cent of the designed load and the reduced PV power may be sufficient for such a load, the altered PV array parameters e.g. array current and voltage may not achieve a perfect matching of the array with the inverter used. Particularly, the array voltage which directly affects the inverter frequency which in turn will alter the rpm of motor and pump. The characteristics of the pump given at 2900 rpm would no longer be valid.

Hence, detailed and long duration experiments are needed to optimize the system installed at off-designed pumping head.

3.5.3.1 Comparison with manufacturers specified output

The method could also be used to test the systems performance under manufacturers specified conditions (33). However, the exercise is not very effective due to inherent characteristics of the system.

The expression used in reference (33) to evaluate the system's performance under manufacturer's specified conditions is the following:

$$V_{ref} = \frac{V_{output} \times E_{ref}}{E_{rec} \times [1 - \beta T_a]}$$

Where V_{ref} and V_{output} are the volumes of water expected on a reference day and received during the field test of limited duration, (m^3)

E_{ref} is the reference solar irradiation ($kWh/m^2/day$)

E_{rec} is the reference solar irradiation received on the plane of the array during the field test.

β is the temperature coefficient,

T_a is the ambient temperature.

The procedure recommends field test for one hour at simulated pumping head equal to the designed pumping head and extrapolating the results to estimate water output under reference specifications.

The distribution of solar radiation follows a profile shown in fig. 3.2. The ambient temperature is also a function of solar intensity, wind speed, soil temperature, humidity etc. The ambient temperature and thus the cell operating temperature vary through out the day resulting in a variation in array conversion efficiency. Similarly, the water table in the well is dynamic. There are some variations (may be very small) in the water table during the period as the pump works continuously from sun-rise to sun-set.

Since the PV pumping system is a dynamic system consisting of more than one sub-systems, whose characteristics change continuously through out the day as the solar and other parameters change, it is difficult to characterise the performance of the system for the whole day using any small quantum of field obtained data.

Also, the expression has a temperature correction term $(1 - \beta T_a)$ for water output received in the field. It would be more accurate to use the term $[1 - \beta (T_{cell} - T_{ref})]$ in place of $(1 - \beta T_a)$, as the coefficient β specifies decrease in cell performance with an increase in its operating temperature with respect to a reference cell operating temperature. Therefore, the reference specifications should include T_{ref} which is the reference cell operating temperature or the reference average air temperature.

In view of the argument above, it would not be an accurate check on the performance of the system under reference conditions, which are inadequate in this case (viz; expected water output 70 m^3 at 20 m head under $6 \text{ kWh/m}^2/\text{day}$).

One possible way to compare the manufacturers claim with actual output is by means of overall system efficiency. The overall system efficiency as calculated from manufacturers specified output is 4.1% for Gual Pahari system and 2.65% for Tilonia system designed for 50 m head. Assuming the maximum motor/pump unit efficiency to be 44% [$\eta_{\text{motor}} = 80\%$, $\eta_{\text{pump}} = 55\%$] and inverter efficiency to be 90%, the array efficiency would then be 10.4%; a figure higher than array maximum efficiency at STC or even at NOCT.

It is apparent, therefore, that the manufacturers claim on expected water output from these systems is on the higher side.

4.0 Social Aspects and Impact Assessment

Major applications of PV pumping systems in developing countries are for rural water supply* and irrigation. While the objective of irrigation pumping using PV powered system is to increase the agricultural output and thus improve the economic status of the community, that of the rural water supply is to meet one of the basic human needs; an access to clean and safe drinking water. The impact of introducing PV technology to a community for irrigation purposes can be analysed on the basis of quantifiable gains over a certain period of time. The benefits accrued to the community by a PV powered rural water supply can at best be felt or sensed through interaction with the beneficiaries. The data being qualitative in nature, is difficult to analyse.

However, a cost-and-benefit analysis of PV technology with other conventional and non-conventional technologies for rural water supply, has been done in more than one case. A study conducted by Meridian Corporation, Alexandria in association with I.T. Power Inc. Washington D.C. for Sandia National laboratory, compared the PV, diesel and hand-pump technologies for rural water supply. The study concluded that PV is least cost option under average insolation and well conditions, for a village population ranging between 80 to 800 persons having a water demand of 40 lpcd. It also highlighted that contrary to conventional wisdom, the per

* Rural Water Supply, throughout this report has been used to consider supply of water for drinking and domestic purposes. A widely accepted target for water consumption is about 40 litres per capita per day (lpcd)

capita initial capital costs of PV systems are similar or even lesser than that of handpump systems which are traditionally considered a low-cost technology (3).

In the present project, PV pumping systems are used only for drinking and domestic water supply to rural communities in different regions of the country. In almost all villages where these systems are commissioned, the original source of drinking water was handpump(s) installed by the local state level agency.

The characteristics and social structure of the communities served, as well as the water utilisation pattern were different at each site. While at Zirpitanda and Teklahalli, water was utilised for all domestic purposes including drinking, community at Tilonia did not use the water for drinking, due to doubts about its purity.

In view of above features, and the small sample size which was interviewed at each site, it is difficult to assess and compare the impact of technology on site specific basis. An attempt has been made, however, to study the social aspects of these systems within a broad framework, based on the survey conducted at each site. It may be mentioned here that the villagers were not asked to contribute towards the finances of the project, i.e. installation costs, maintenance cost etc. as this was a demonstration project.

4.1 Approach

4.1.1. Information collection:

A questionnaire based survey was conducted by the TERI team at sites where systems are commissioned. Two separate questionnaires were developed in consultation with the DNES; one to study the response of rural community served by the system and the second for the nodal organisation. The first questionnaire solicited information regarding the use and effectiveness of the system which was collected through personal interaction with persons from a few randomly chosen households in the community served. The second questionnaire was developed to collect information regarding the maintenance of the system by the nodal organisation. A major portion of the questionnaire was filled by the TERI team based on the observed status of the system during the visit, the rest was based on direct interaction with a representative of the nodal organization.

The surveys were conducted by the TERI team during its post-installation visit to each site. The duration of each trip was 3 to 5 days excluding travel time. Annexures 4a and 4b present both the afforesaid questionnaires.

Survey was conducted at five out of the seven sites where systems are commissioned. The site at Gual Pahari, is situated within the TERI campus and hence, no rural community is served by this system. The water is mostly utilised for social forestry plantations at the campus. The survey at Sikkabamin could also not be conducted during the post-

installation visit to the site. As gathered from the nodal organisation (RWD, Government of Arunachal Pradesh), the PV motor/pump unit was removed from the borewell after the TERI team had commissioned it in June 1989 and the handpump was installed in the same well. Later, the PV pumping unit was reinstalled. On checking, it was found that three-phase motor pump unit was not connected to the inverter in proper configuration, making it rotate with low rpm, resulting in much lower output than expected. The community was not satisfied with the performance of the system and wanted the handpump installed back on the borewell. Although, the electrical connections were set right and the water output increased substantially, the situation was not conducive to conduct any survey during the visit as the community was not really benefited by the system till then.

Table 4.1 lists the total population/households of the community served and the sample surveyed at each site.

Table 4.1 : Details of the Communities Surveyed

Site	Size of the Community	Surveyed Sample
Teklahalli (Karnataka)	125 population	13 households
Zirpitanda (Maharashtra)	800 population	21 households
Tilonia (SWRC, Rajasthan)	100 population	11 households
Golaghati (Tripura)	100 households	18 households
Indrapura (REDA, Rajasthan)	650 population	12 households

Additional information regarding installation cost etc. was obtained from the Public Health Engineering Department (PHED) Rajasthan which had borne the entire cost of installation including the digging of borewell for the Indrapura site in Rajasthan. The PHED, as part of its regular programme of supplying drinking water to villages, took care of the entire installation cost for the PV system in Indrapura where it had originally planned to dig borewell and install handpump on it. The figures (given in Annexure 4c), are used for comparing the unit cost of water pumped using PV, with that of diesel.

4.1.2. Impact assessment:

The collected information was categorized and the impact of these systems on rural community was assessed on the basis of the following:

- (i) Reliability and availability
- (ii) Acceptability
- (iii) Affordability
- (iv) Community participation
- (v) Operation and maintenance
- (vi) Cost implications.

Suitability/appropriateness of the technology and its application in drinking water supply has been analyzed as per the above assessment and discussed in section 5.0.

4.2 Reliability and availability

Of the seven commissioned systems, those at Gual Pahari Tilonia and Sikkabamin were non-operational once each due to minor technical problem. At all three sites, the electrical connections were found to be loose which had caused the system to stop functioning. At Tilonia, the array wire connections in the array junction box had become loose. They were set right and system was made functional by the SWRC staff itself. The Gual Pahari system also faced the problem due to loose electrical connections from the inverter to the motor/ pump unit.

The system at Sikkabamin was reported non-functional by the user organisation, five months after the post-installation visit to the site by TERI team. The fault which was repaired by the nodal organisation staff was reported to be loose electrical connection only.

Other than the problem of loose electrical connection, no technical fault was reported or found at any commissioned system. The array, the inverter and the motor/pump unit of all the systems are functioning continuously from sunrise to sunset for more than one year in different climatic conditions.

The failure or non-functional state by itself is only partial indicator of the system reliability and

availability in the field*. Adequacy of water for the daily needs of the community is also an important factor. Volume of water for rural water supply is characterised by an almost constant monthly demand. It is critical to have water available on demand, therefore the water storage becomes an important parameter of rural water supply.

Assuming a figure of 40 lpcd as a target for rural water demand, the maximum output from the system installed in Gual Pahari is suitable for a community having a population of about 1300. A community of about 550 persons would have an adequate supply of water even in the month of february when the output from Gual Pahari system has been at its lowest. If the system was installed at its design conditions, the water (59.4 m^3 daily as estimated for 20 m system) would have been adequate for a community of approximately 1480 persons.

The daily water output record from Gual Pahari also shows that the system pumps water throughout the year and is functional even during monsoon months. Hence, in a typical installation, the system output is adequate throughout the year for a community of 500 persons, with one handpump as a standby to take care of system failure and other such problems. The system thus proves its field reliability to be good.

* Correct parameters to judge the system reliability and availability in the field are mean-time-between-failure (MTBF) and mean-down-time (MDT). A typical MTBF for diesel pumps and hand-pumps is 1,500 hr (34). MTBF and MDT have not been calculated for PV pumping systems under study due to the occurrence of failure only once each in three out of seven commissioned systems.

4.3 Acceptability

Acceptability of the technology and system by user community is sensitive to many factors. These factors range from clearly defined ones as the performance/failure of the system in the field, to completely invisible ones e.g. social rivalries and enmities. Both these factors, were encountered during project implementation, yet the final acceptability of the system has been good in all cases.

Acceptance of the system by the user community has been analysed both at site-specific and at general level, based on the responses during conducted surveys.

Particular questions in the questionnaire for user community indicative of the acceptability, are numbered 3, 4a and 5 (annexure 4a). In five out of six cases, the source of rural water supply was either a handpump or an open well. Physical labour was involved in lifting water from these sources. At Tilonia, a diesel pump was used to supply water for domestic applications. The drinking water was fetched from handpump only. In all these cases, the community admitted the saving in terms of labour and time due to the introduction of PV pumping systems. As the procurement of water for drinking and domestic applications is mostly done by the female population of rural community, the survey at Tilonia highlighted the relief and ease provided by the PV pumping system to the female population towards their daily domestic responsibilities. At other sites, female population was not available for interaction. One beneficiary pointed

out the ease with which a child can procure water from PV system. Majority of the individuals rated the system performance for rural water supply as good after observing it for a substantially long period of time. The need for storage tank was felt at sites where it was not constructed. This need was felt after observing the performance of the system during cloudy days and also for requirement before sunrise and after sunset hours. Some beneficiaries, however, felt that the water was adequate for the community even during cloudy days and storage tank was not critically needed. Beneficiaries also asked for a better distribution network which included pipelines and taps to various places inside the village. One person mentioned the advantage of minimal maintenance requirement and a few felt that more such systems should be provided to neighbouring villages.

To summarise, the response of the user community towards the introduction of a new system was indicative of its general acceptance. Specific problems pertaining to acceptability at certain sites are discussed in subsequent sections.

4.3.1 Doubts regarding the purity of water: Tilonia

The SWRC community was fetching drinking water from handpumps while supply for other domestic chores was met by diesel pumpset installed in the borewell. The hand pumped water is considered pure and hence, suitable for drinking and cooking purposes. Diesel, considered an unclean fuel and

unhygienic, is not accepted as a fuel for pumping. Water pumped by the diesel pumpset is not used for human consumption at this place. Interestingly, the belief was not changed with respect to the PV pumping system as it was found during survey. The entire community continued to use handpump for lifting drinking water, although it was understood very clearly that the sun is the only fuel required to pump water using PV systems. Probably, the borewell which was dug inside an open well having unusable dirty water and the use of a machine to lift water, kept the community away from using it for drinking purposes.

An attempt was made to explain and make the community understand certain simple facts e.g. same borewell could be used to install handpump or PV pumping system, hence water in both cases would be same, and the PV pumping system does not in any way affect the quality of water. However, such beliefs and ideas can not be eradicated suddenly. It is a gradual process and the community would take time to accept PV pumped water for human consumption.

4.3.2 Unsuitable for irrigation: Golaghati

1 The village community in Golaghati is familiar with PV pumping systems used for micro irrigational purposes. Although the PV pumping system under study is meant for drinking and domestic water supply, the community looked at it critically from irrigational point of view. More than fifty per cent of the beneficiaries who were interacted with, observed that the system is unsuitable for irrigation due to

its low discharge. One even pointed that unlike diesel pumping set, the PV pumping system can not be shifted from one farm to another for irrigation.

It appears, that for Golaghati community the maximum benefit of PV pumping system lies in its application for irrigation. Also, the majority of people use PV pumped water only for drinking purposes which initially was obtained from handpump. Other domestic activities are performed near the river for which river water is used. The PV system which is commissioned near the place of maximum public activity, is used only for drinking water applications. The impact, thus, is not so visible for Golaghati community which has earlier been benefited by PV pumping system supplied for micro-irrigation.

4.3.3 Dissatisfaction due to low output: Sikkabamin

The problem related to acceptance encountered in Sikkabamin is due to the implementational aspects of the project at the site.

Since the PV pumping system replaced the handpump which was the only source of drinking water to the community, the performance of the PV system was critically monitored by the beneficiaries. During the monsoon months, the PV pumping system had to be removed and the handpump was reinstalled on the borewell. On installing the PV pumping system once again on the same borewell, the electrical connections to the motor/pump unit were not made right. This resulted in low rpm of the unit and hence low water output.

The replacement of a handpump by PV pumping system (the former more reliable than the latter, as observed by the community) generated anger among the beneficiaries which resulted in strong opposition to any post-installation civil works. It was only after the connections were set right and full output of the PV pumping system was shown to the beneficiaries, did they accept the system.

The problem encountered in Sikkabamin is a typical, yet a critical example of non-acceptability of any new technology or system due to its inappropriate implementation in the field.

4.3.4 Social rivalry: Indrapura

The commissioning of system at Indrapura, REDA site in Rajasthan was delayed due to social rivalry between the sarpanch of identified village and the neighbouring one.

Unofficial reports indicated the resistance offered by the village neighbouring the identified village Indrapura, towards transportation and installation of the system in Indrapura. In the absence of details available with TERI, the exact nature of the problem and the solution could not be discussed in the report.

The system was successfully commissioned in the village after sorting out the rivalry between neighbouring villages which took almost one full year.

4.4 Affordability

The high investment cost of a PV pumping system mean that some donor agencies will have to be involved at different stages for financing any such village project. In this case, the systems were donated by French organisation, the project implementation was supported by the DNES and installation costs were borne by the local state-level agency. The villagers, although were not asked to contribute anything towards the finances of the project at any stage, few were agreeable to pay minimal charges towards the services provided by the system. Since it is a community facility provided by the local state level agency, who is expected to make arrangements for supply of drinking water to the village, the community in general, did not consider the system as a privilege and perhaps did not show any enthusiasm for making any payment towards the service provided.

As for owning the system for private land irrigation, almost all beneficiaries at Zirpitanda (Maharashtra) and Golaghati rated the PV system based on its performance as comparable with conventional electrical motor pump set. The majority would have considered buying the PV system up to 2.5 times the cost of electrical motor/pump set. A few were eager to own the system at 3 times the cost of electrical motor/pump set, while one beneficiary at Zirpitanda was willing to pay up to 4 times.

Beneficiaries at Teklahalli and Tilonia do not own any land and therefore, did not reply to this particular

question, which is numbered 4b in the questionnaire for user community. Indrapura community also did not reply to the question.

The mixed response during the survey indicated that farmers did consider purchasing this PV pumping system after observing its field performance, though the high capital cost was an inhibitive factor.

4.5 Operation and maintenance

An important aspect of proper operation of PV pumping system is the effective utilisation of water through appropriate distribution network. Ideally, one closed water tank for storage of drinking water and two open storage tanks for other domestic purposes and for livestock drinking should be constructed at each installation site. Pipes and taps should also be provided.

The water distribution network, although not as elaborate as the one described above, has been constructed/ was being constructed at all PV pumping system sites. The water which is wasted due to spilling etc. is planned to be used for growing vegetables by all nodal organisations.

Maintenance aspects associated with PV pumping system can be categorised into daily or routine maintenance and fault repair. Certain basic routine O&M principles were communicated to the representatives of nodal organization during the two day workshop in the manual given to them (Annexure 2B).

The nodal organisation was asked to depute one person who could be one of the beneficiaries, to do the routine maintenance of the system. During the post-installation trip, the cleanliness of the array was observed to be poor in all sites except Teklahalli in Karnataka. Wire connections were found loose and leakage of water observed in 3 out of 5 sites.

The systems at Zirpitanda and Sikkabamin were found to have one module surface broken in their respective PV arrays. While at Zirpitanda it was reported that the module was hit accidentally by a stone, the reason for broken module at Sikkabamin could not be gathered. As only the surfaces are broken, both the modules were found to be contributing effectively towards the overall electrical output of the array. Their performance is not deteriorated and they have withstood the rainy season without developing any short-circuit or corrosion induced faults.

Both the installations have been provided with fencing to the array which has obviously not proved effective towards such accidents or involving stone throw.

Except at Indrapura at all other sites the staff of the nodal agency took the responsibility of the routine maintenance of the system and log-book was kept up-to date at Teklahalli, Zirpitanda and Tilonia.

Although, none of the systems have had to face any major breakdown during the entire project duration, the

probability of one occurring in the future can not be ruled out. The important requirement for any such fault repair is a responsive repair service with a sufficient inventory of spares and technically skilled manpower. Primarily, the donor organisation should supply an inventory of necessary spares on a routine basis. The nodal organisation should identify one person which could also be a beneficiary, to undergo training in fault repair either conducted by the implementing agency or by the donor itself.

In the current project, no such repair service is made available on a long term basis. The implementing organisation viz. TERI imparted the basic training on installation and O&M aspects of the system to the representatives of nodal organisation who are now responsible for the O&M of their respective systems. However, the inventory of spares is not available either with the implementing or nodal organisation as it has not been provided by the donor of the systems. One nodal organisation, the DSTE, Tripura had contacted the supplier through TERI to buy an inverter and keep it as spare. There was no reply from the supplier.

4.6 Community participation

Community participation is initiated at the level of project planning itself. While identifying a village which could be proposed as one for the PV pumping system installation, an assessment of the need for the technology cannot be done without the participation of the community

concerned. Next, the most appropriate location for installing the system can also not be identified without the involvement of community.

Quoting Dennis Blamont in ASVIN Newsletter No. 4 (19), 'It seems utmost necessary that before the installation of the pump, an agreement on the base lines of the project is reached by the beneficiaries; in fact they should be made to ask themselves for the implementation of the programme and not being asked to accept it''

Subsequently, at each state of the project, the co-operation of the community is important. The community is the actual owner of the pumping system and the project implementation is only a motivator for familiarising the beneficiaries towards maintaining and managing the system in future.

In the implementation of the project, the active participation of the community to be served, was sought at the site selection stage itself. Direct interaction with the beneficiaries during the site selection visits played a significant role in choosing a village for installing the system. At the installation stage, the communities did not extend any co-operation but acted like mere observers. Similarly for routine maintenance of the system, no voluntary help came from the community until a token payment was offered. Even then, the maintenance responsibility is given to the staff of nodal organisation in majority of cases.

The project from the view of community participation has not been any different from several other community welfare programmes promoted by the state level agency. Strictly speaking, the community remains a beneficiary of that particular system or service without having to contribute anything either in terms of money or physical labour.

The case of SWRC, Tilonia is different. It is a closed community of about 100 persons living and working towards meeting the objectives of the organisation. The campus is developed for the community by the community. The PV pumping system, as a part of the infrastructure of the campus and thus the community, provides a good example of community participation particularly on its O & M aspects.

4.7 Cost implications

The cost of delivered water i.e. Rupees per m^3 for PV pumping system has been calculated to be Rs. 3.15 as per the table 4.2. The calculations are based on following assumptions:

1. The entire cost of installation including digging the borewell would have been same for Gual Pahari and Indrapura system (Details of installation cost for Indrapura is provided in Annexure 4c)
2. Total system cost at the time of purchase to be Rs. 2,50,000 only as indicated by the donor.
3. The annual water output from Gual Pahari system in the year 1989 is $15,261.5 m^3$

4. Overall system life is 20 years
5. Annual O&M cost is nil based on the field experience.

Table 4.2: Cost of pumping from the PV system

Items	
PV system cost (Rs.)	2,50,000
Installation + civil work (Rs.)	1,09,235
Total (Rs.)	3,59,235
System life (years)	20
Capital recovery factor at 12% discount rate	0.1039
Total annual cost (Rs.)	48,101
Total water output (m^3)	15261.5
(kWh)	374.3
Cost of delivered water ($Rs./m^3$)	3.15
(Rs./kWh)	128.5

This figure would reduce to Rs. 2.20 per m^3 or Rs. 89.8 per kWh if only the cost of building the foundation for the array is considered in place of the active cost of civil work done. The cost of digging the borewell, constructing storage tank and distribution network would be common for any technology considered. Hence, for comparing the cost of ⁴water pumped using PV, diesel or grid electricity, the figure of Rs. 2.20 per m^3 is more appropriate.

Table 4.3 calculates the costs of delivered water using diesel as the energy sources.

Table 4.3: Cost of water pumped using diesel motor/pump set

Item	
Specific fuel consumption (ml/kWh-gross energy)	320
Overall system efficiency (%)	15
Specific fuel consumption (ml/kWh-useful energy)	2133.00
Cost of diesel in 1989 (Rs./litre)	4.00
Fuel cost (Rs./kWh)	8.53
Capital cost of the system (Rs.)	8500
System life (years)	10
Capital recovery factor at 12% discount rate	0.1770
Annual capital cost component (Rs.)	1504
Annual O&M (@ 10% of the capital cost (Rs.))	850
Annual (Capital + O&M) cost (Rs.)	2354
Annual fuel cost (Rs./kWh)	3192.8
Total annual cost (Rs.)	5546.8
Energy delivered (kWh)	374.3
Cost of energy (Rs./kWh)	18.84

Cost of energy or delivered water in case of PV pumping system is approximately 7 times the cost of energy using a diesel pump set. The PV pumping system may not appear cost-competitive in comparison to diesel pump set, the benefits accrued to the community by a reliable and environmentally clean source of rural water supply can not be overlooked.

5.0 Project Assessment

A systematic approach towards solving the problem of safe and hygienic rural water supply using renewable energy sources involves: (i) an assessment of total water requirement and availability, either in terms of daily water demand or on monthly basis, (ii) comparison of available water pumping technologies, and finally, (iii) the selection of the most appropriate one.

There are many considerations for selection of a renewable energy technology. Broadly, they can be classified as follows (2):

Technical feasibility

- availability of energy source, climatic and topographic conditions, existing technological infrastructure, field evaluation report and case studies, O&M aspects

Socio-economic feasibility

- social acceptability of energy source and device, potential for productive water use, cost effectiveness of the energy device.

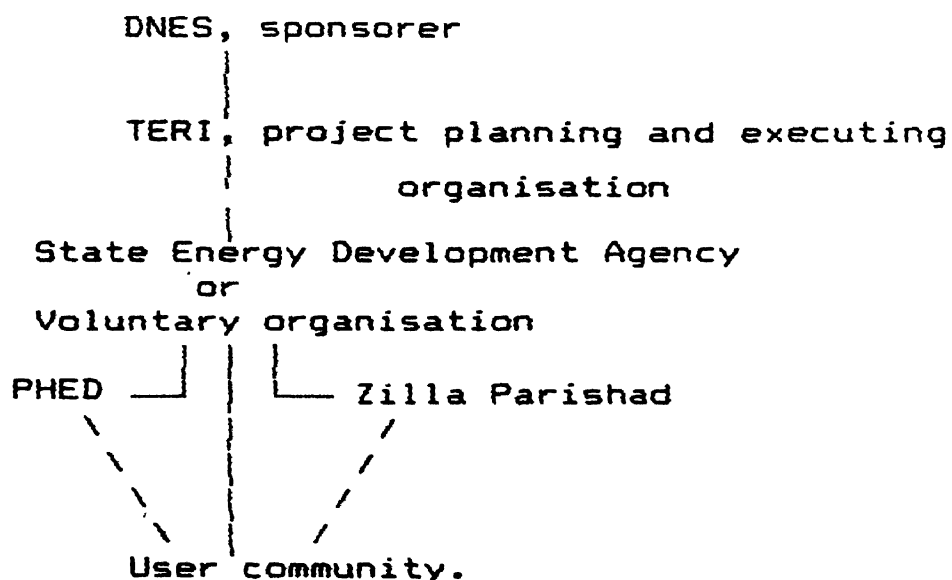
Once the most appropriate renewable technology has been identified, the operational details with regard to identifying the product and the supplier, developing project implementation methodology, user training, etc. can be worked out.

The objectives of the present project, however, were different from the conventional approach discussed above.

The project did not deal with the selection of appropriate technology for rural water supply, instead, selection of appropriate sites for already available energy devices, introducing the technology to the community i.e. installation and commissioning and finally, assessing the suitability of the device for rural water supply based on its field performance at different sites.

In view of these objectives and adopted approach for each, the project assessment also has many dimensions. While one way of assessing the project is to critically judge how far the adopted methodology has been successful in project implementation, another way is to analyse the suitability of the technology and device for the application they were used for in the project.

The project implementation involved more than one organisation, shown in the chart below:



The methodology developed for site selection, installation and commissioning and performance evaluation required an effective co-ordination to be maintained with State level organisations throughout the duration of the project. As it appeared, the co-ordination could not be maintained so effectively with a few organisations. While the methodology could not achieve a very detailed, and thus more specific site selection activity, it was effective in successfully installing most of the systems. The problems encountered in the overall implementation of the project and their probable reasons have been analysed and discussed in subsequent sections.

5.1 Effectiveness of the approach

5.1.1 Site selection

The site selection was planned to be done in three phases; (i) asking state level agencies to propose sites based on the site specifications provided to them within a certain fixed time frame, (ii) discussing all proposed sites individually during the two day workshop and, (iii) visiting short listed sites to select the one for installation. As per the planned methodology, the final phase would have included visiting a few short listed sites which were already visited by the state level organisation either before or after the second phase of the project.

During the first phase of site selection, six organisations out of seven who were contacted, proposed few sites as per the specifications provided within the given time frame.

For the second phase of site selection, only five sent their representatives for the two day workshop. During the discussion on 'siting and end-use management', it appeared that none of the sites proposed were conforming to the specification provided. There were probably two reasons for their inability to propose suitable sites:

1. After seeing the system installed at Gual Pahari and through discussions during workshop, the representatives could understand better the requirements of a suitable site, which could not be communicated to them effectively through written correspondence.
2. Two out of five representatives had visited the sites before proposing them for PV system installation. They, therefore were aware of details regarding the topography, existing water resources, actual water requirement etc. others had collected site data from records of various concerned departments. The discussion on such proposed sites was not found very effective towards considering them for the installation.

All five representatives were asked to collect data on more sites after visiting each of them so that the third and final phase of site selection would be executed.

During the third phase, certain typical problems associated with a field implementation programme were encountered. These problems were partly due to the infrastructural constraints and certain preferences of involved state level and other agencies. Although, the third

phase completed the site selection procedure as planned, the final selection of site for installation was a compromise between the technical suitability of the site and constraints/preferences of involved organisations.

The specific problems encountered are classified as follows:

5.1.1.1 Database for drinking water needs

The data on water level, yield of the borewell, water requirements etc. were sought from the records of Ground Water Survey Department, which was not available in all cases. During the final site selection visit to all proposed sites, the information collected was found different from the records. In addition, the test rig to do the borewell yield test was not readily available. Actual yield test could be conducted only in Maharashtra. In Karnataka, the rig could not reach the site due to a minor failure on the highway.

A thorough survey of the entire region was needed to choose sites having required water level and borewell yield. This could be done effectively if the database on drinking water needs was available at district or block level. None of the state level organisation conducted detailed site survey before proposing sites at any stage of the site selection. As a result, all systems are installed at sites offering much less than the design pumping heads for these PV systems. Also, the system commissioned at selected borewell in Karnataka had to be removed because the borewell had

collapsed; the yield was much less than that required by PV pumping system and shown in records.

5.1.1.2 Administrative aspects

Problems related to administration were encountered in two cases. Maharashtra presented a typical example of such administration related deterrents. The deputy engineer of Zilla Parishad, Jalna district who was selected and sent as a representative by MEDA to attend two day workshop at TERI, was transferred to another district Parbhani before the site in Jalna could be finalised and system installed. This resulted in some delay in site selection as both the Zilla Parishads (Jalna and Parbhani) identified and proposed new sites for the installation. Since a few sites in Jalna had been shortlisted earlier, the system was installed at one of the sites in Jalna without the supervision of the MEDA representative who had attended the workshop and learnt about the system O&M procedures.

A similar situation of the participant of the workshop not supervising the O&M of the system, was also faced in Arunachal Pradesh. The RWD representative who had attended the workshop, was stationed at the division different from where the system was installed. The representative, therefore, could not make himself available after the system was commissioned at chosen site.

5.1.1.3 Constraints and preferences of state level agency

Any village level activity or implementation of the project at village level cannot be co-ordinated effectively

without the support of an agency actively involved in that region. TERI, being a Delhi based organisation, co-ordinated the project at different sites with the infrastructural support of state level or other local organisation. The constraints, as also the preferences of concerned organisations therefore, could not be overlooked during project implementation.

The basic objectives of one of the voluntary organisation contacted, did not match with the objectives of the project. Hence, the organisation withdrew from the project after a site was finalised for installation. MYRADA, in Karnataka, although was interested in participating in the project by helping in installing one of the systems at its proposed sites, did not want the system for any community welfare purpose. MYRADA's main activity is developing micro-irrigation by supplying pumping systems to individuals. The PV pumping system under study, were essentially meant for rural water supply and could not be given to any individual. Also, the experiment, as per MYRADA, is not replicable, i.e. it is beyond the financial capability of an average farmer to procure more such systems in case the demand is created by introducing one system to an individual or a group.

MYRADA, thus, did not participate in the project although the site proposed and selected was suitable for PV pumping system installation.

Generally speaking, the constraints and preferences of concerned organisations played significant roles in site selection.

5.1.2 Installation and commissioning.

Five out of seven systems were installed and commissioned by TERI. The remaining two, both in Rajasthan, were installed by the respective nodal organisations (SWRC and REDA). The approach followed for installing these systems included three main activities:

- * Installing one system at Gual Pahari, TERI campus in order to familiarise with the system, to learn installation procedure and to observe the system performance.
- * Conducting a workshop for representatives of prospective nodal organisations to make them understand the system, its installation procedure and basic O&M requirements.
- * Installation and commissioning of rest of the systems under the supervision of TERI.

The approach followed was found effective in installing the systems, except that the time schedule could not be maintained. Only two systems could be commissioned within the total duration kept for site selection and installation. Two more systems were commissioned within three more months, while the commissioning of remaining three was delayed substantially. The time limit fixed for installing the system at most of the sites, was extended due to problems described below:

- * Site in Maharashtra could not be finalised before the onset of monsoons. Transportation of the system from Jalna headquarters to the site and installation was delayed due to monsoons.

- * Access to the site in Arunachal Pradesh was difficult. Road transport was unreliable due to disturbances in Assam while air transport was frequently affected by bad weather. The planned trip to Arunachal Pradesh within the time duration fixed for installation had to be cancelled midway due to problem in air traffic. Replanning of the trip delayed the installation in Arunachal Pradesh.
- * Site selection took a long time in Karnataka due to inability to propose suitable sites by the nodal organisation, delaying the installation.
- * The installation at Indrapura (Rajasthan) was delayed due to specific local problems discussed in section 4.3.4. Similarly, SWRC Tilonia also installed the system as per the convenience of the organisation.

The installation and commissioning activity did not face any major problem. A few field related ones are listed below:

- * **Availability of manpower:** In most cases, the labour was provided by the staff of nodal organisations. The manpower from the village community, even for some minor job, was not available. In Jalna (Maharashtra) where the Zilla Parishad had to depend on locally hired labour mostly from village community, the installation work was delayed by one day as an agreement on wages could not be made.
- * **Delay in procuring required material:** The nodal organisations were given a list of the entire material required for installing the array, in addition to their

representatives being told the entire installation procedure during workshop at Gual Pahari. Even then, the required material was not available at the site. In most cases, it was the communication gap between the head office of the nodal organisation and that at the sub-division level. The office at sub-division level was not fully equipped with pipes, bends particularly the water meter.

- * **Storage of system at site:** The entire installation including the construction of foundation and grouting of array structure normally took three full days. All the components of the system were at the site for approximately 36 hours before the system was commissioned. No storage place was available for these components and in all cases, the panels, inverter and pumping unit had to be left in the open space for one night.

5.1.3 Performance evaluation

The project implementation involved co-ordination of state level organisation in providing infrastructural support during site selection and installation and collecting daily output data on their respective systems. The nodal organisations were given standard format and were explained the procedure for collecting data everyday for the limited duration of the project. For a more detailed performance evaluation, TERI had formulated a different methodology for which the data was collected by the TERI team at each site.

In spite of repeated reminders from TERI and occasionally from DNES, only two organisations, SWRC, Tilonia and KSCST, Bangalore kept a record of daily water output. The co-ordination between TERI and state nodal organisations proved ineffective in motivating the latter to study the performance of the system in the field. Brief records provided by each organisations have been listed in section 3.5.1.

The data provided by SWRC Tilonia could not be used for performance evaluation because the system was switched on during a few hours of the day as per the requirement in certain months. As the water requirement was fluctuating in different months, the excess array power was utilised for alternate applications.

Other than the problem of unavailability of data supposed to be collected by nodal organisations and general ineffectiveness of the communication towards monitoring, specific problems encountered during data collection by TERI team are listed here:

- * The post-installation work including construction of storage tank and appropriate water distribution network had not been completed in three out of six sites visited. As a result, the impact of complete installation for the maximum benefit of the user community could not be studied. In Arunachal Pradesh, the water meter was not installed even after one year of commissioning the system. No data could be collected on the system in spite of the

visit by TERI team to the site for the specific purpose of data collection.

- * The system commissioned at the chosen site in Karnataka, had to be shifted to another site as the borewell yield was found inadequate. This had resulted in a significant delay in implementing the project in Karnataka. The post-installation visit to Karnataka site was undertaken in the season not very favourable for performance evaluation of the recently installed system.

5.2 Suitability of the device for chosen application

Basic considerations for selection of the appropriate technology, viz., technical, social and economic feasibilities, are significant factors for assessing the suitability of the device. Particularly, in this project which dealt with utilization of a new device for a certain application, the suitability of the device can be assessed effectively based on above factors.

The appropriateness of the device for a particular size of community based on the output data has already been discussed in section 4.0. This section assesses the device on the basis of specified considerations.

5.2.1 Technical feasibility

Technical feasibility of PV pumping system in the field depends on the suitability of system with respect of climatic conditions, performance of the system and on how effective the infrastructure is towards its operation and

maintenance. Also, to an extent on what is the field performance history of similar systems in different regions.

Several case studies are available for field performances of PV pumping systems, using crystalline silicon PV array. One of the recent study discusses all aspects, viz., installing, financing, operating and maintaining PV pumping systems in Mali which has a total of 157 systems. The study entitled 'Learning from Success - Photovoltaic Powered Water Pumping in Mali' reported the field work performed between May 1989 and November 1989, for U.S. Committees on Renewable Energy Commerce and Trade, U.S. Department of Energy. Systems studied included surface motor/submerged pump and submerged motor/submerged pump (34).

In India, PV pumping systems have been in use for a long time. Recently, the use of submerged AC motor/multistage pump has also been started for medium and deep well pumping applications. DNES has initiated a few R&D and demonstration programmes with an aim to develop suitable systems for Indian conditions.

The most critical requirement for technical feasibility of PV pumping system is availability of solar irradiation throughout the year. In India, most regions receive abundant solar irradiation with maximum days of clear sunshine in an year. Several PV systems have been commissioned in regions where sites for PV pumping systems under study are located. These regions included both the states of Arunachal Pradesh and Tripura.

Other climatic parameters critical for PV system installation and operation are availability of even and open land and wind velocities. These parameters are also favourable at all chosen sites. Hence, none of the climatic factors pose any short term or long term problem to PV pumping systems.

A critical requirement of device chosen for rural water supply is its availability and reliable field performance throughout the year in every season. The systems under study have proven their suitability for chosen application viz; drinking and domestic water supply as they are able to pump water in every season irrespective of climatic variations in water table.

Although, PV pumping systems are characterised by low maintenance requirements as compared to other renewable technologies, the technical skills required are high. As per International Reference Centre for Community Water Supply and Sanitation, The Hague, maintenance of PV pumping requires a visit by a mobile team of qualified technicians once or twice a year.

In this project, the state level organisations are responsible for the O&M of PV systems in their respective states or region. In most cases, these state level organisations are Energy Development Agencies, who co-ordinate and manage renewable energy related programmes in their states. The agencies, thus, have required

infrastructure to monitor and maintain renewable energy systems including PV devices commissioned in the region.

Specifically for PV pumping systems under study, no such infrastructure has been created at any level except in Tilonia. The SWRC campus, Tilonia uses PV systems extensively for lighting and other power applications. The system integration, installation including construction and fabrication of a few balance-of-system components is done at local level. The technical skills required for O&M of PV systems have been developed within the campus.

The system supplier has also not given any training at any level for operating and maintaining the system, a practice which is followed routinely. Neither have any spares being provided by the suppliers. The state level organisations do not have any inventory of spares specifically required for PV systems under study.

5.2.2 Socio-economic feasibility

One of the basic principles of rural water supply programmes is the community participation. It is also essential to assess the impact of new pumping device on the local situation. The formulation of some form of local organisation e.g. water committee help in selection and supervision of local pump caretaker, to arrange for collection of water charges etc. Such an exercise would form an independent, site specific activity which in itself would require long term efforts of development workers at

each site. This exercise did not fall within the scope of the project.

For a short term project like the present one, it is difficult to assess the long term social acceptability, self-developed skills and infrastructure within the community to manage the programme in future, use of extra water for small plot irrigation and other productive work etc. Based on the the conducted survey, it appears that the local community at each site acknowledges the reliability of the device and finds it viable for rural water supply.

A preliminary analysis carried out in section 4.0 indicates the viability of the system for rural water supply. The cost of water in such cases is not the only decisive factor for selecting the appropriate technology. Social and environmental benefits are equally important.

The capital cost of pumping system powered by PV can be reduced in large scale production for National Rural Water Supply Programmes. The total capital cost of the system indicated by the donor includes a very high cost of PV module; almost US\$ 13 per W_p . Assuming the PV module price in the range of \$5-6 per W_p , the capital cost of the system has already decreased substantially. The cost of delivered water in terms of useful energy will than be much lower.

Outcome of the studies like the present one would help in gaining experience regarding performance of these devices under various Indian field conditions, adapting and modifying

the technology to local conditions, improving existing designs and develop methods of involving the communities in such programmes. It is highly desirable to increase self-reliance at both national and local level.

Testing and monitoring of various existing systems at the level of universities and research institutes would help in familiarizing concerned community, both at national and local level with the new technology and system.

The current project has been an exercise at the level of DNES, TERI and state nodal organisations in this direction.

6.0 Conclusions

Technology

- * The study has provided an opportunity to understand and gain first hand experience on different aspects related to PV pumping systems and their use for supplying drinking water to rural areas of India. These include individual components, their integration and overall system design, procedural details for installation, commissioning and coordination, long term field performance and issues associated with social impact of technology on users.
- * Based on the technical performance of these systems in various regions of the country, they have been found viable for rural water supply applications to far and remote communities.

Site selection

- * Sites selected for installations have been a compromise between their technical compatibility with the system both in terms of water depth and end-use requirement, and the preference/constraints of the nodal agencies involved.
- * Overall system efficiencies obtained in the field have been lower than theoretically calculated value on account of the off-design pumping head installation in all cases. Performance measured at simulated pumping head close to the designed one has indicated an improvement in the overall system efficiency.
- * For proper matching of the PV pumping system to the proposed site, precise information on water table depth,

well yield, permeability of aquifer, population of the community, specific water requirements, appropriate distribution network, available water resource and ongoing rural water supply scheme in the region is desirable. In other words, a base-line information regarding water requirement should be available. This information would be more effective for planning any such project if it is available at district or even block level.

Commissioning and monitoring

- * Four out of seven nodal agencies, could not keep a record/log book of daily performance of the system. Also, no specific person either from the staff of nodal agency or from the beneficiaries, has been given responsibilities to look after the routine operation and maintenance requirements of the systems in these four cases.
- * The maintenance requirements are minimal in PV systems yet fault repair often require technically skilled manpower and adequate inventory of spares. Although it was not within the scope of the project, yet no permanent infrastructure, except that available with nodal renewable energy agencies, has been created to take care of specific maintenance and fault repair of the system in future.
- * No inventory of spares been made available by the system supplier on the routine basis.
- * Design and construction of an effective distribution system, with an adequate user participation, should form an integrated activity of the installation itself.

Future and long term programme

- * The execution of any such project at community level could perhaps be done more effectively if the Energy Development Agency (EDA) as also the End-Use Department (EUD) are involved in the project. While the EDA would coordinate installation, operation and specific maintenance of the system, involvement of EUD is essential for selecting sites compatible with the system in terms of end-use requirements. The EUD would also take the responsibilities of the routine O&M of the system as it has a more spread out infrastructure in the concerned region. Appropriate EUD for such a project would be the one managing rural water supply scheme.
- * These systems, if considered for irrigation, should be distributed to individuals/groups belonging to one region only. Giving one system to a large community in different regions of the country would not be very effective on account of their limited capacity. Instead, distributing these systems to small group of individuals belonging to the same region and willing to share the benefit of pumped water would help in developing the chosen community socio-economically. The chosen community should not have any migratory population as the impact of introducing irrigation cannot be assessed unless the facility is utilised by the same community on a long term basis.

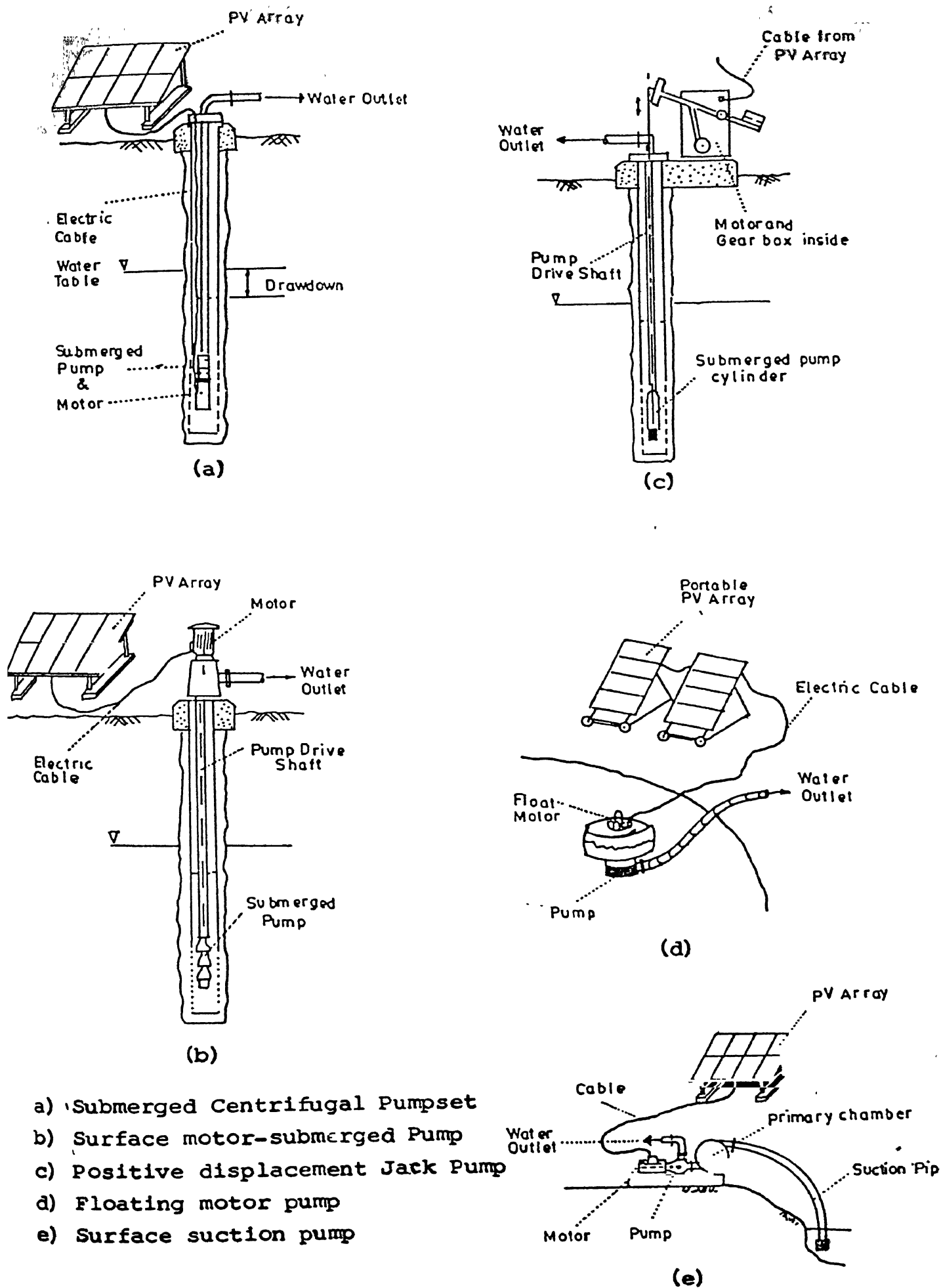
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- a) Submerged Centrifugal Pumpset
 b) Surface motor-submerged Pump
 c) Positive displacement Jack Pump
 d) Floating motor pump
 e) Surface suction pump

Fig.1.1 : Pumpset Configuration

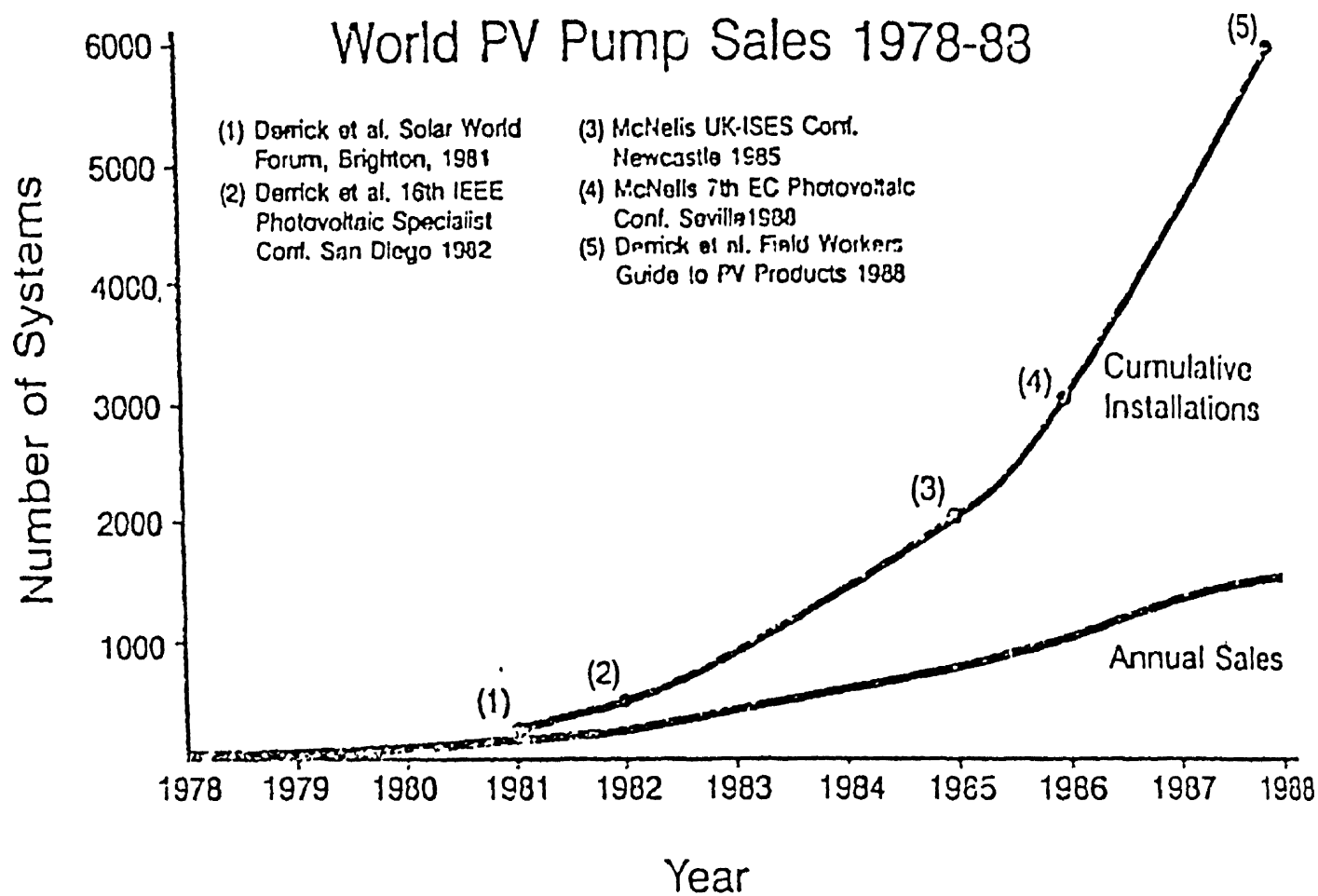


Fig. 1.2 : World PV Pump Sales (Ref. : 10)

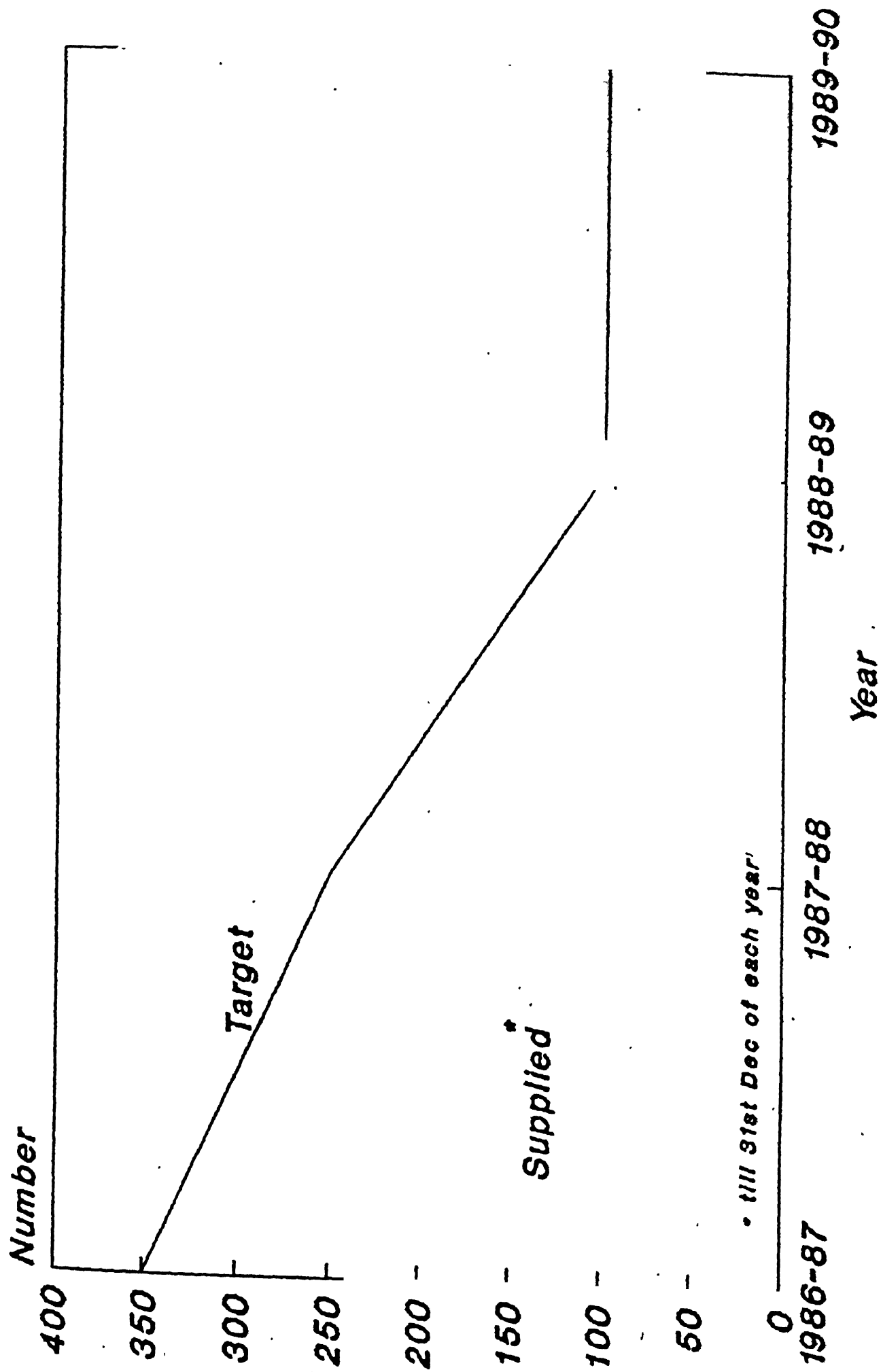


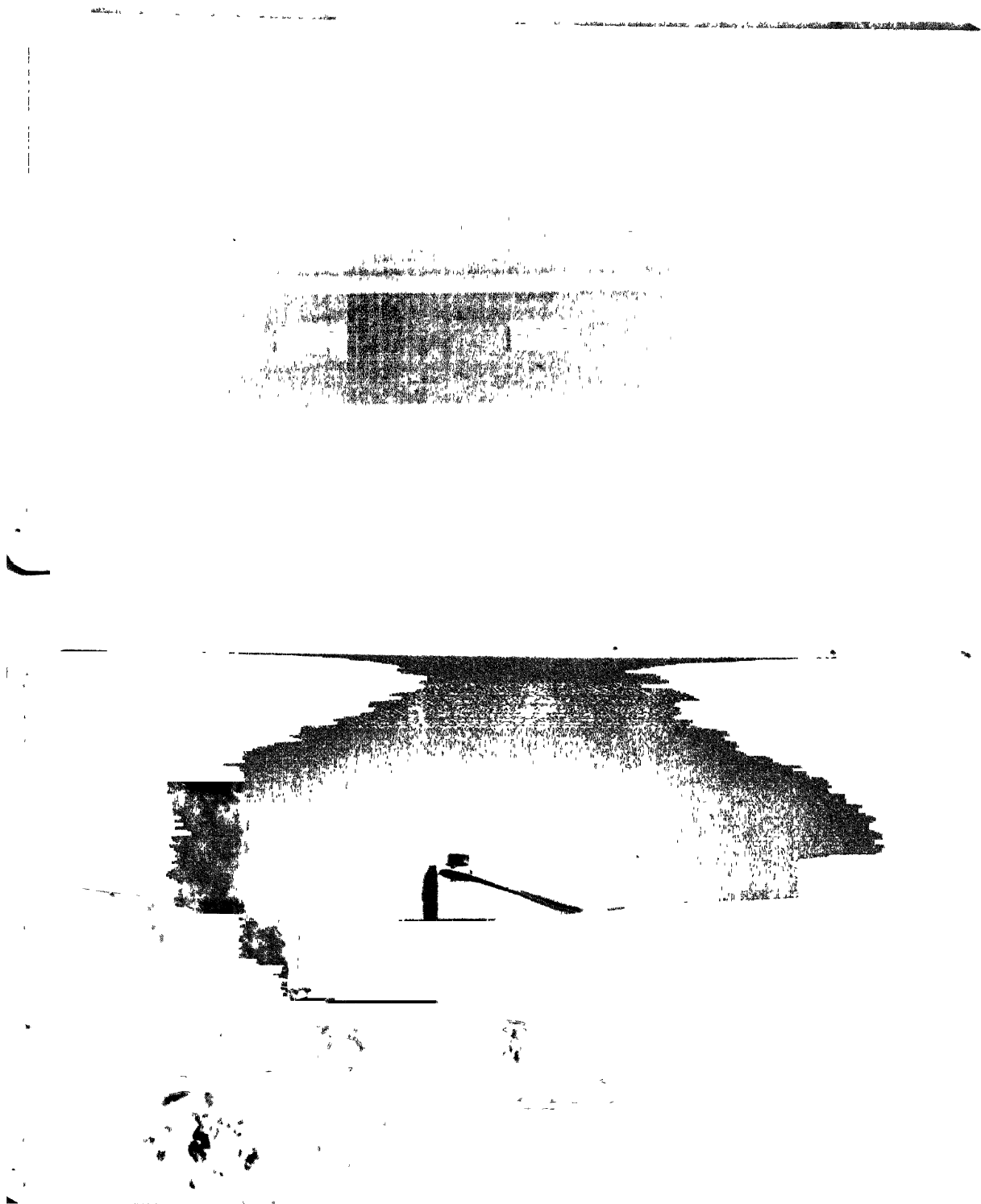
Fig. 1.3 : PV Pumping Systems supplied by the DNES

Gual Pahari (Haryana)
(a)




Golaghati (Tripura)
(b)

Fig. 2.1 : Commissioned Systems at Seven Sites



Tilonia (Rajasthan)
(c)

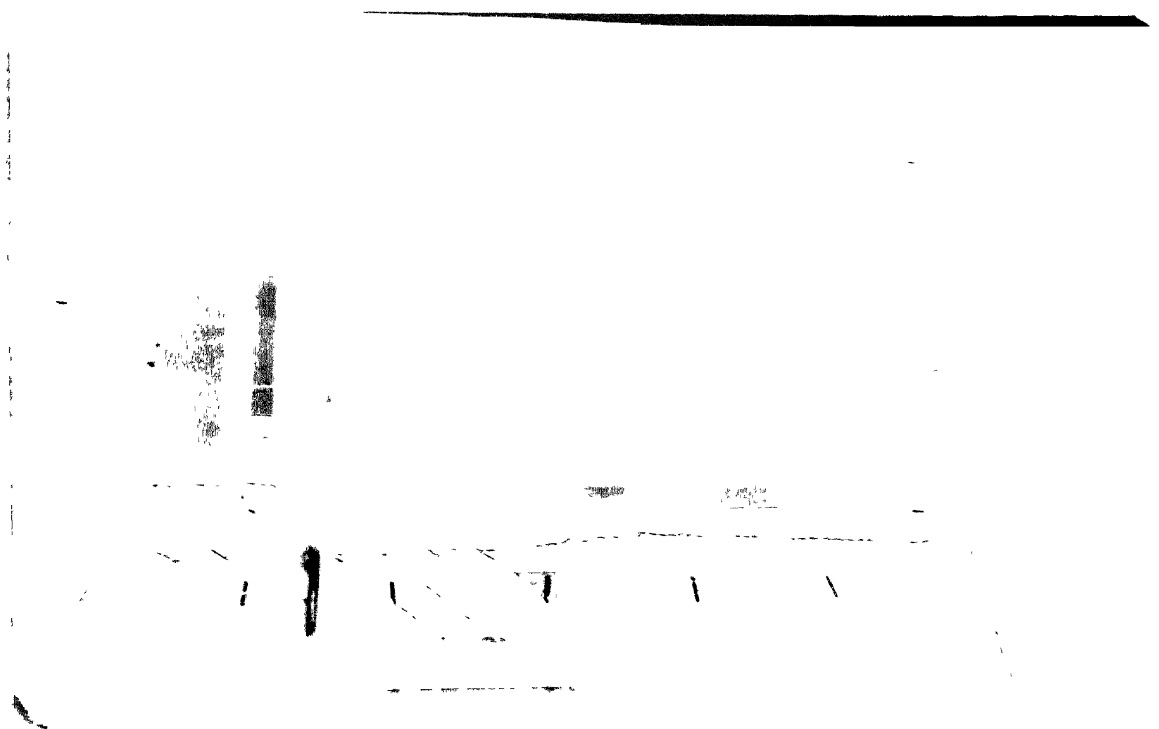


Sikkabamin (Arunachal Pradesh)
(d)

Zirpitanda (Maharashtra)
(e)

Indrapura (Rajasthan)
(f)

Teklahalli (Karnataka)
(g)



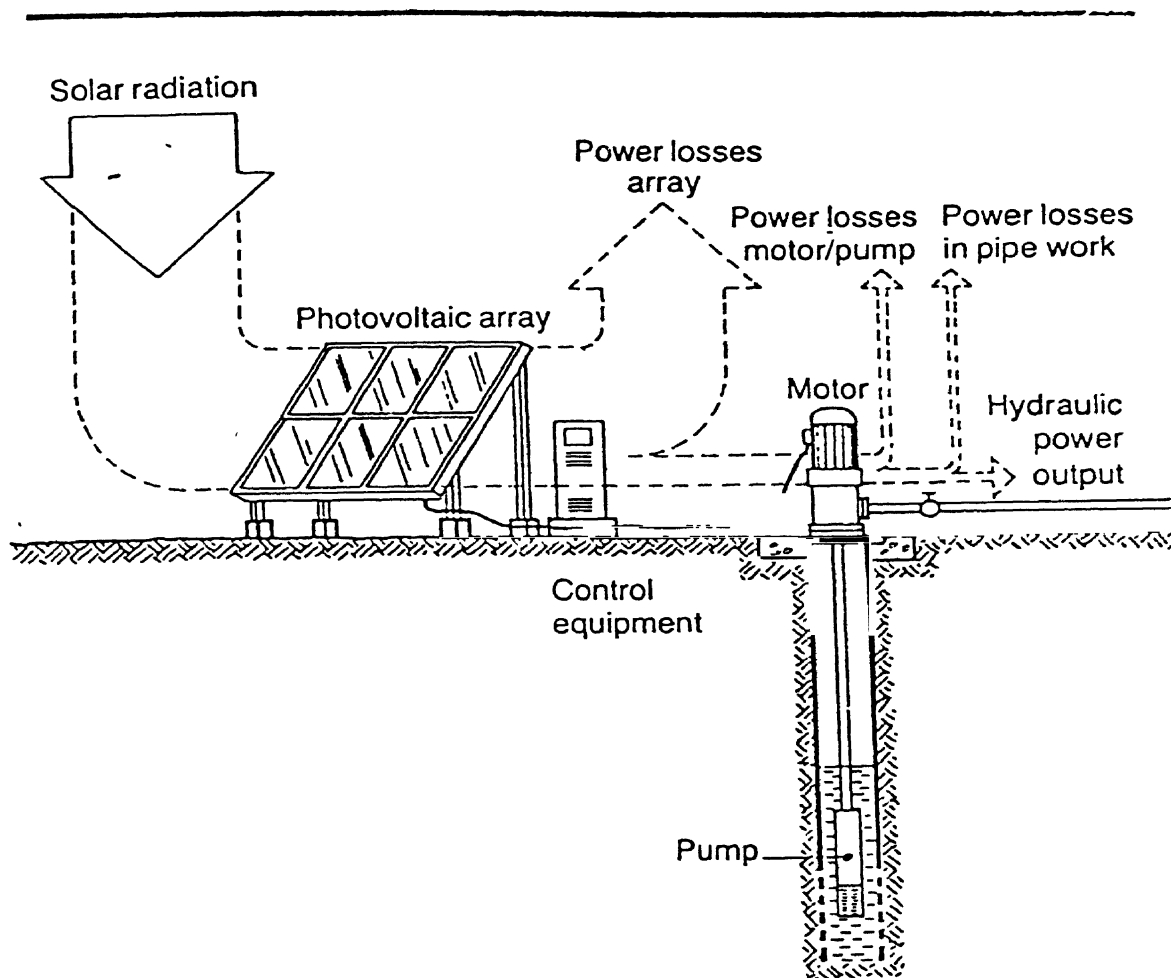
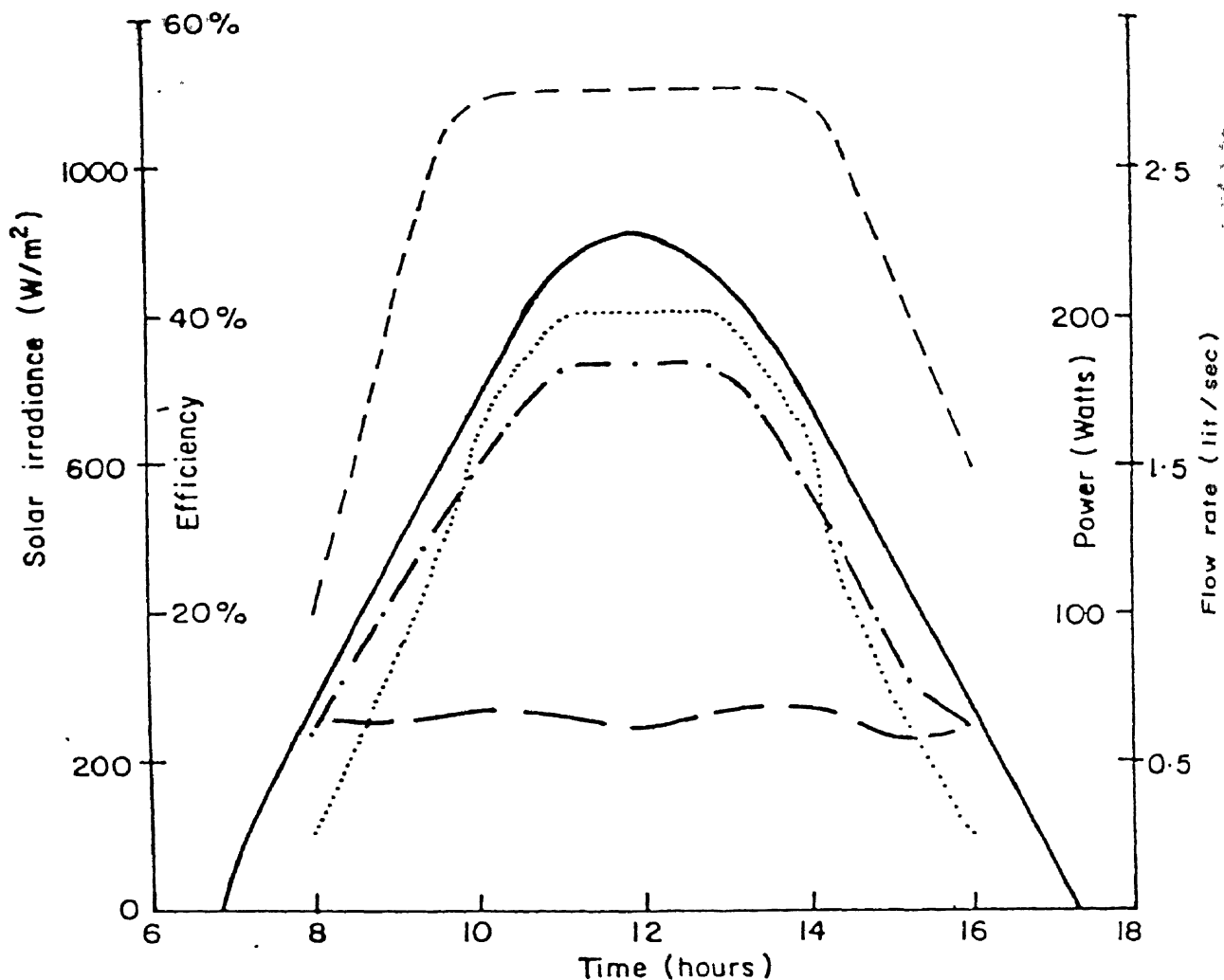


Fig. 3.1 : Power Conversion in PV Pumping System (Ref. 2)



KEY

—————	Solar irradiance
—————	P.V. array efficiency
- - - -	Sub - system power efficiency
- - . - . -	Array electrical output
.....	Water flow rate

SYSTEM PROPERTIES

Array rating = 250 W_p
 Solar irradiation = 25 MJ/m²
 Array electrical outputs = 3.9 MJ
 Sub - System energy efficiency = 50%
 Total head = 5 m
 Water output = 40M³

Fig. 3.2 : A typical day's operation of a solar pump with power conditioning. (Ref. 22)

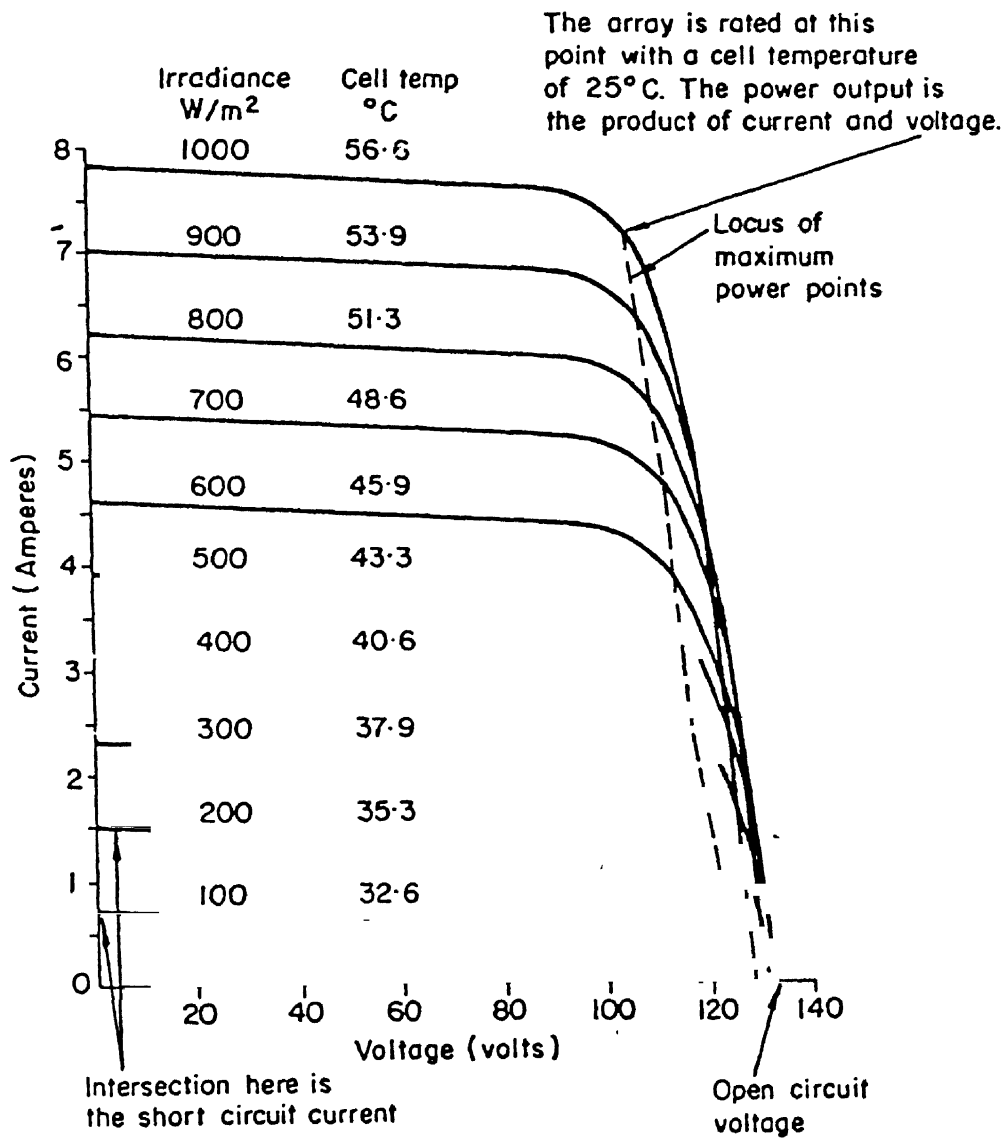


Fig. 3.3 : I-V characteristic curve of PV array (Ref.: 22)

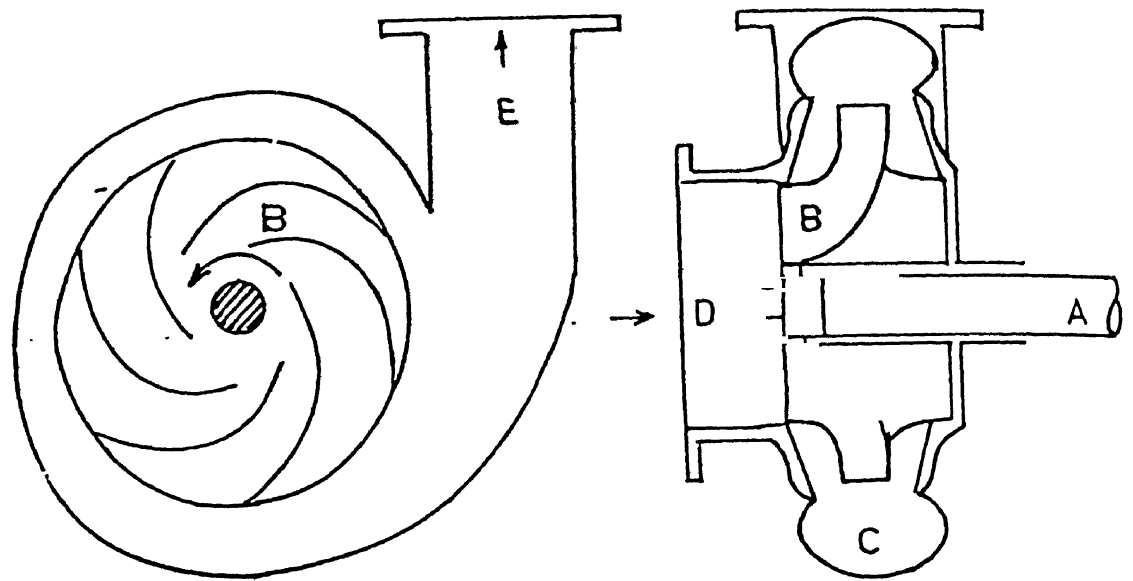


Fig. 3.4 : A simple centrifugal pump

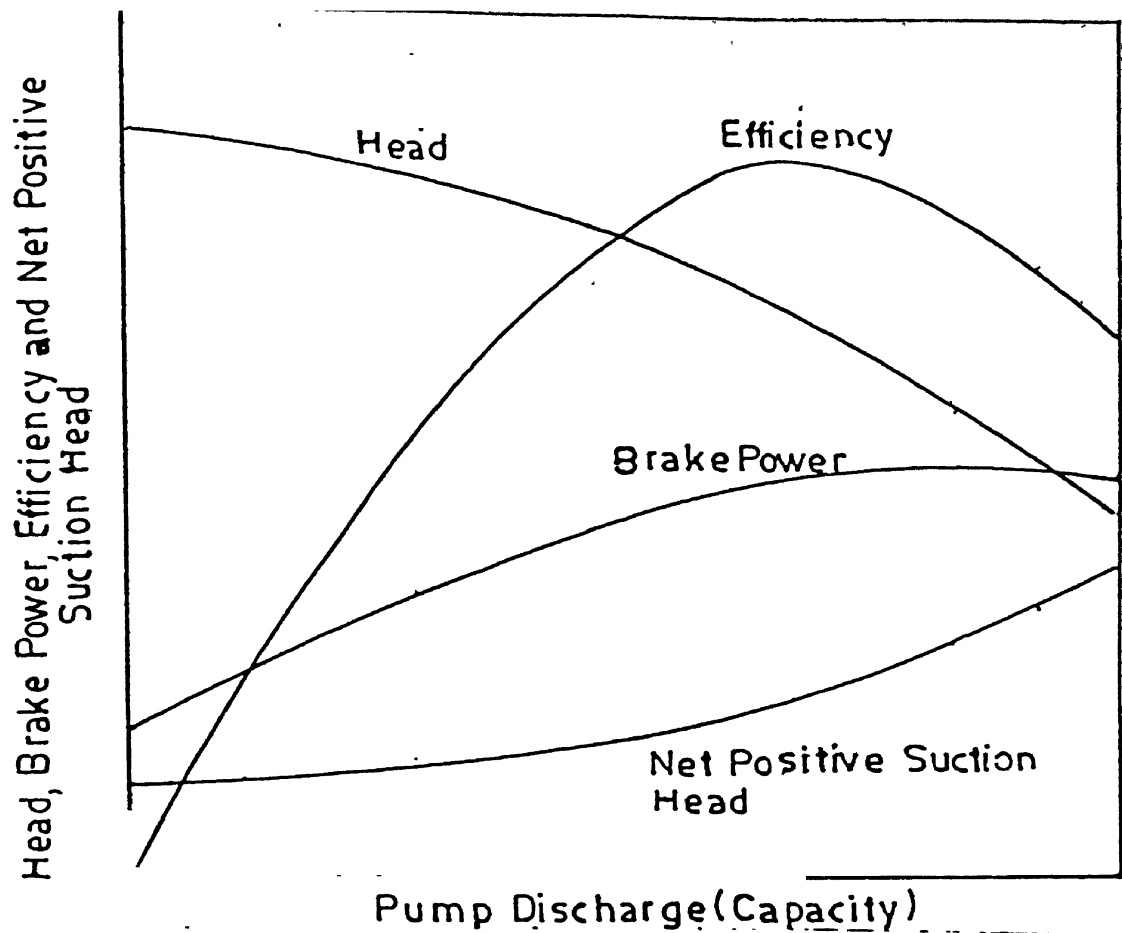


Fig. 3.5 : Characteristic curve for a single stage Centrifugal pump

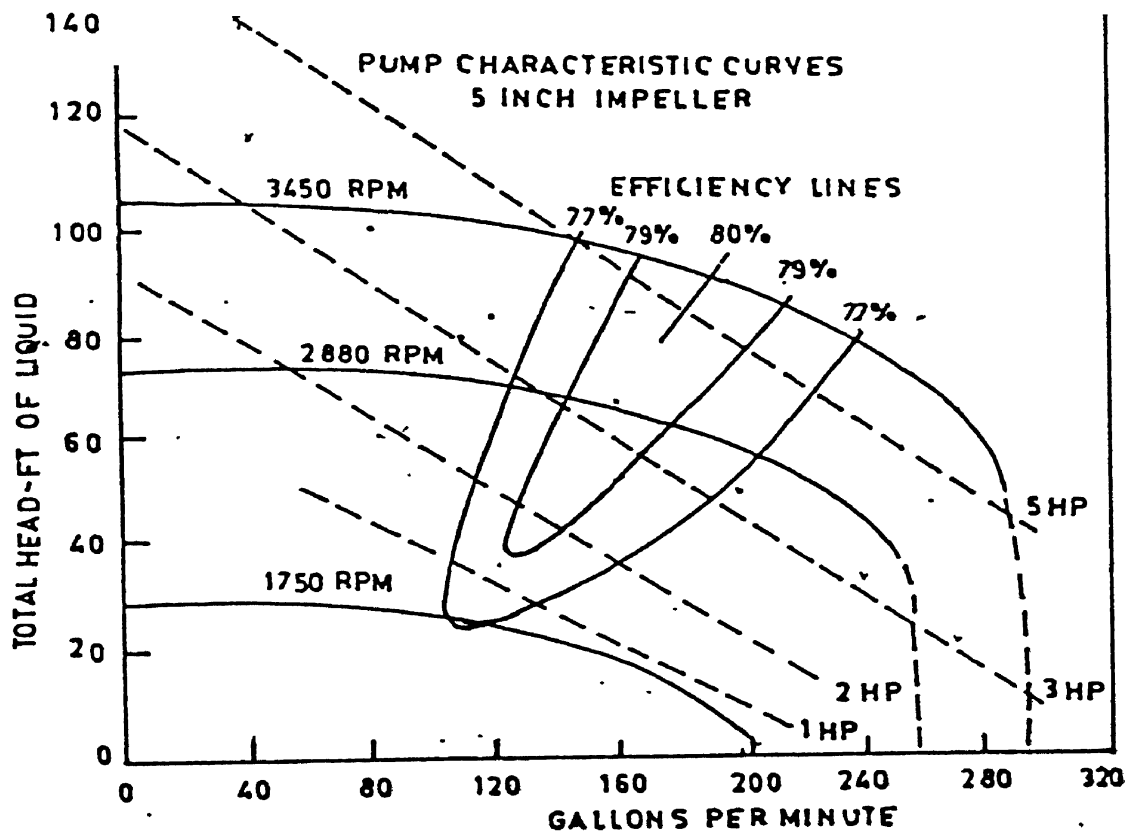


Fig. 3.6 : Characteristics curves of a centrifugal pump at various speeds

PHOTOVOLTAIC SOLAR MODULE

TYPE BPX 47 402
40 W — 12 V

HIGH RELIABILITY BI-GLASS SERIES MULTICRYSTALLINE SILICON

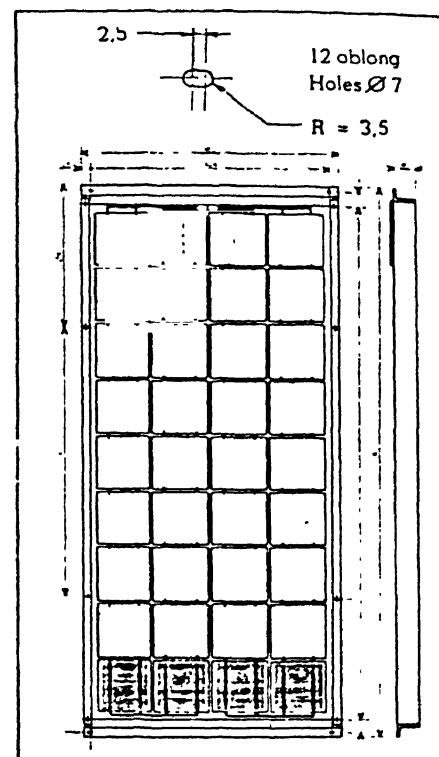
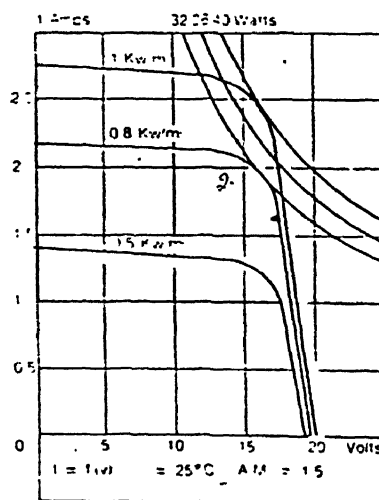
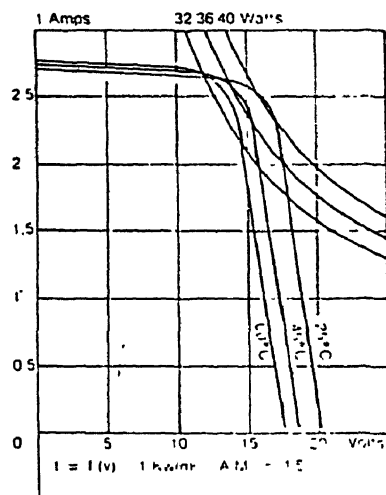
Many years of on-site experience and efficient technical research have provided improvements of technology leading to the famous bi-glass module BPX 47 402 and its exceptional level of reliability.

The manufacturing quality and the performance stability of this module permit PHOTOWATT to give exceptional guarantee conditions.

This high reliability module is specially designed to withstand the most severe environmental conditions and is suitable for any application :

- telecommunication
- water pumping
- cathodic protection
- beacons
- village power
- educational TV
- hospital/bush dispensary

CHARACTERISTICS



Weight : 6.8 kg
Packed dimensions : 1 unit = 1 060 × 485 × 65 mm
4 units = 1 090 × 490 × 210 mm

Typical data at 1 kW/m², AM 1.5

Junction temperature	Tj	(°C)	25	45	60
Nominal voltage		(V)	12	12	12
Maximum power	P max	(W)	40	36.4	34.8
Voltage at Pmax	V max	(V)	16	14.3	13.1
Current at Pmax	I max	(A)	2.5	2.54	2.58
Short circuit current	Isc	(A)	2.74	2.80	2.84
Open circuit voltage	Voc	(V)	20.2	18.5	17.4
NOCT (0.8 kW/m², 20 °C, 1 m/s)		(°C)	43		

Values given at ± 10 %

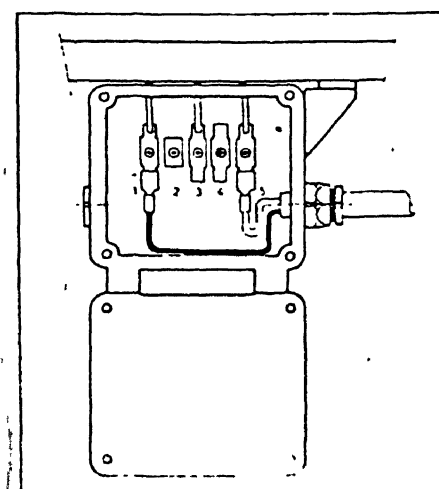


Fig. 3.7

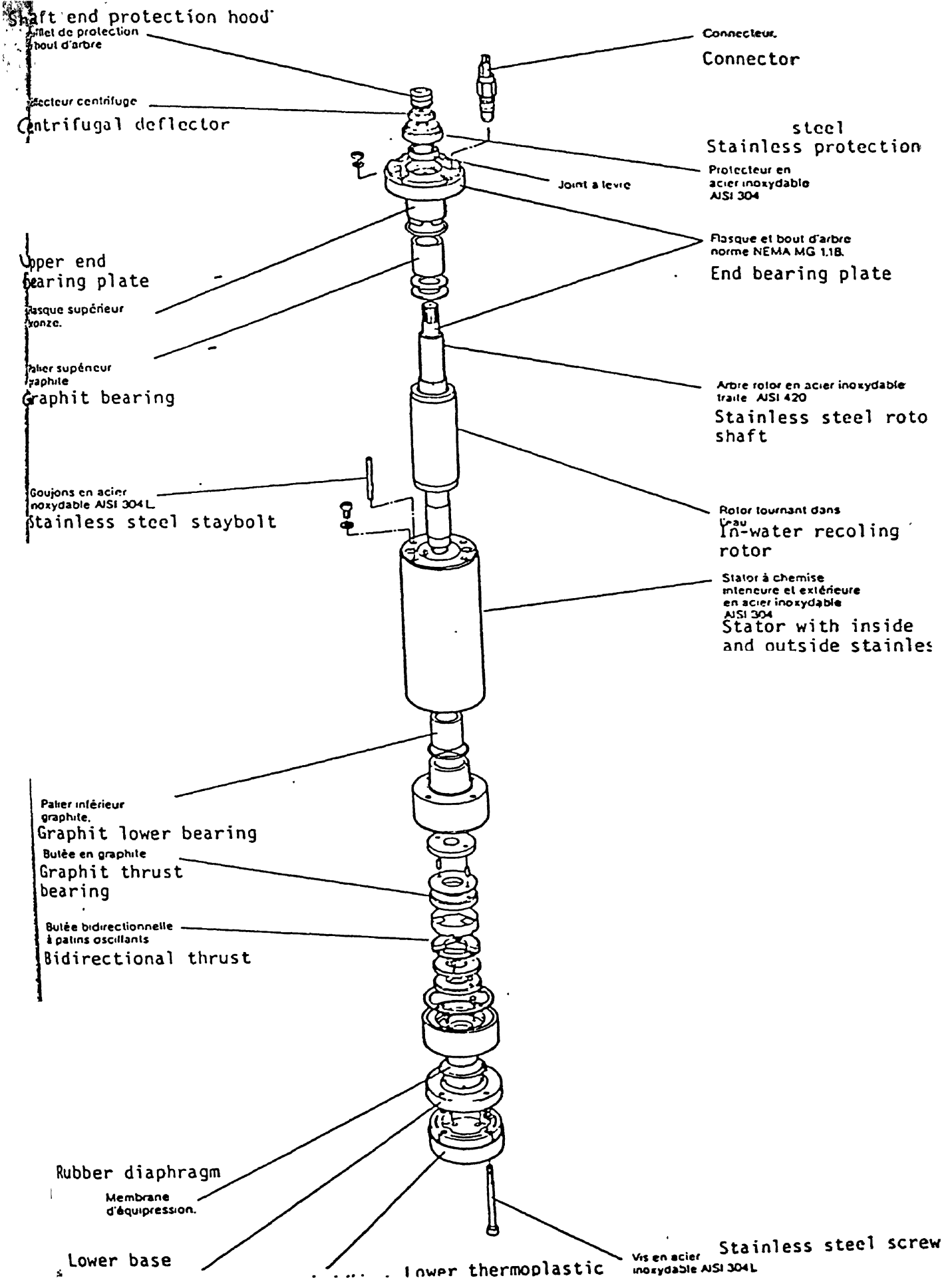


Fig. 3.9 : Submersible 4" AC motor

ARMOIRE ONDULEUR

INVERTER CABINET

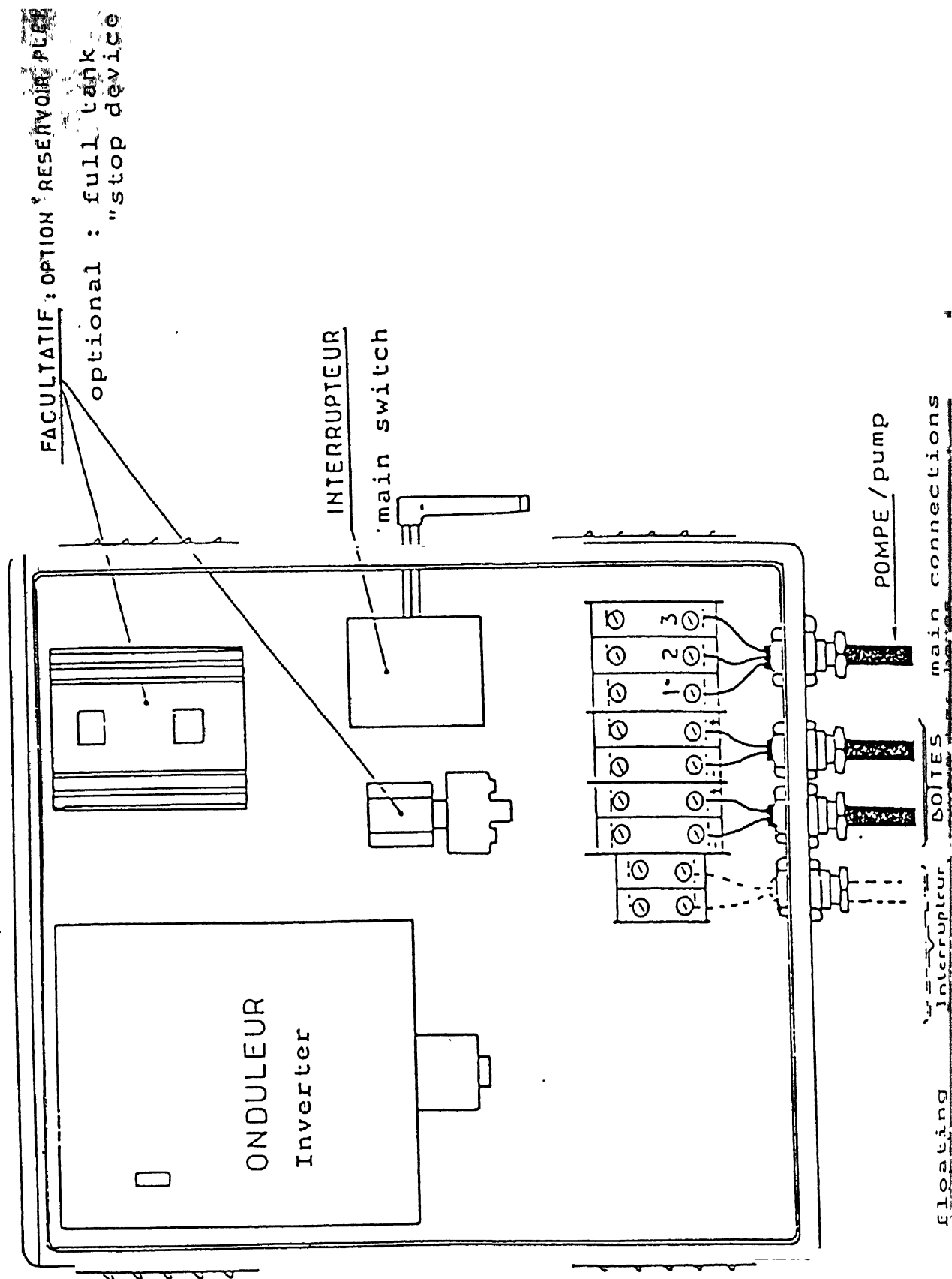


Fig. 3.8 : Inverter Cabinet

Orifice de refoulement Ø 1" 1/4

Type	Nb étages	Puisance absorbée		Débit en m ³ /h en fonction de la H.M.T. en m à 2900 tr/mn																	Hauteur H m	Poids kg		
		$\sqrt{C_h}$	kW	10	15	20	30	40	50	55	60	70	75	80	90	100	110	120	130	140			150	180
RA 5	5	0.5	0.37	6.8	5.2	4.55	2															456	3.65	
RA 7	7	0.75	0.55	6.1	5.6	5.2	4.1	2.5														529	4.3	
RA 10	10	1	0.75		6	5.7	5.05	4.2	3.2	2.6	2											638	5.15	
RA 15	15	1.5	1.1			6.1	5.7	5.25	4.8	4.55	4.3	3.6	3.25	3	2							821	6.9	
RA 20	20	2	1.5				6	5.7	5.35	5.2	5.05	4.7	4.5	4.35	3.8	3.3	2.6	2				1056	8.6	
RA 30	30	3	2.2					6.1	5.85	5.75	5.65	5.4	5.3	5.2	5	4.8	4.55	4.25	3.95	3.6	2.85	7	1421	11.65

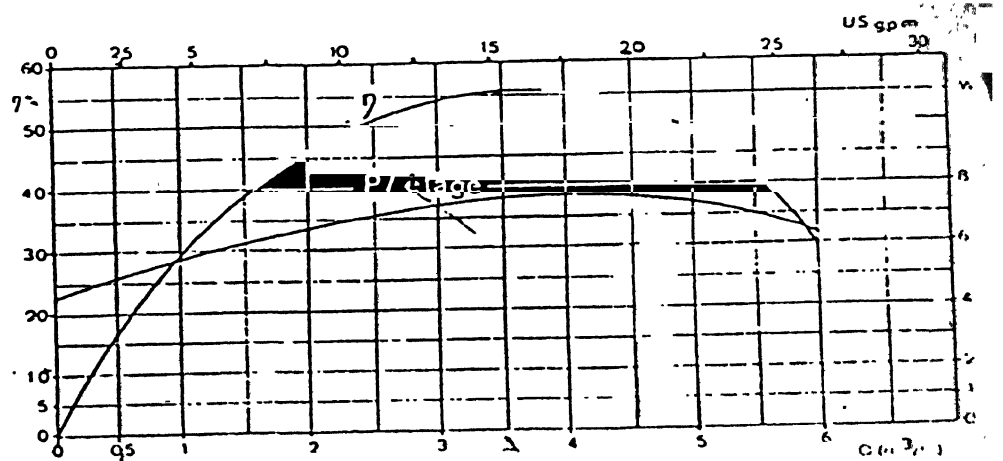
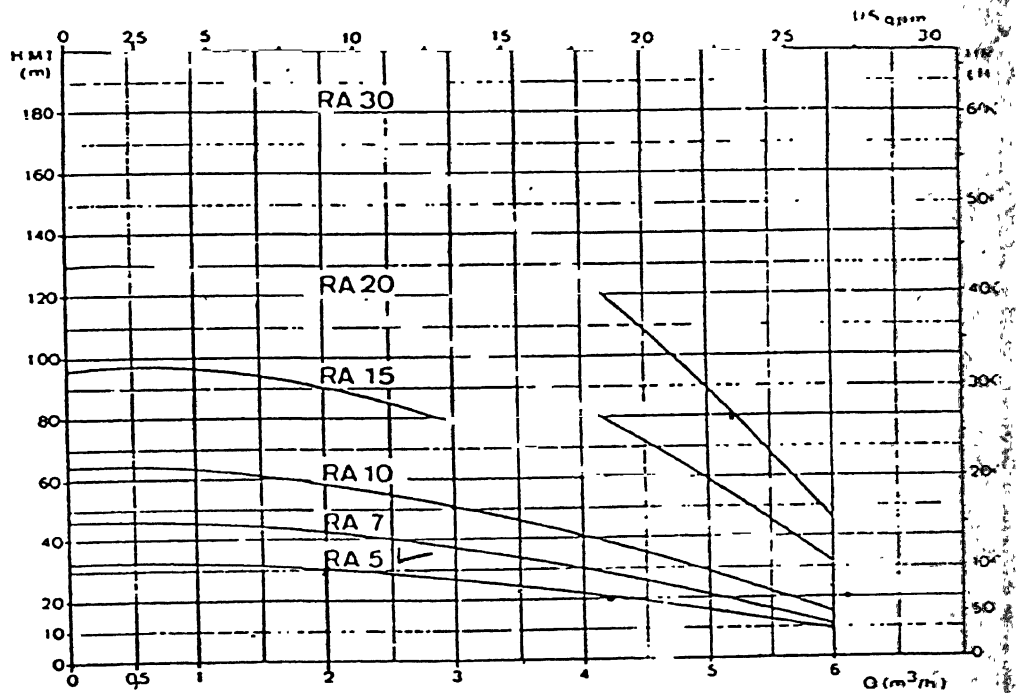
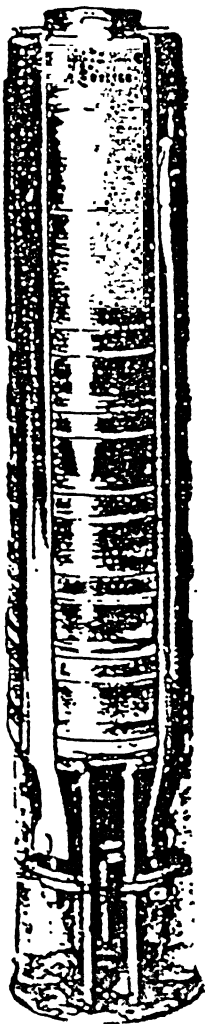
Stages Power

M3/H flow rate according to T.M.H. at 2900 rpm

Height Weir

Caractéristiques de fonctionnement à 2900 tr/mn

Characteristics of operation at 2900 rpm



Grains cor fondes : L... 150 25/3, cl... C...
 Les 1 m... 1... 1 m... 35 C...

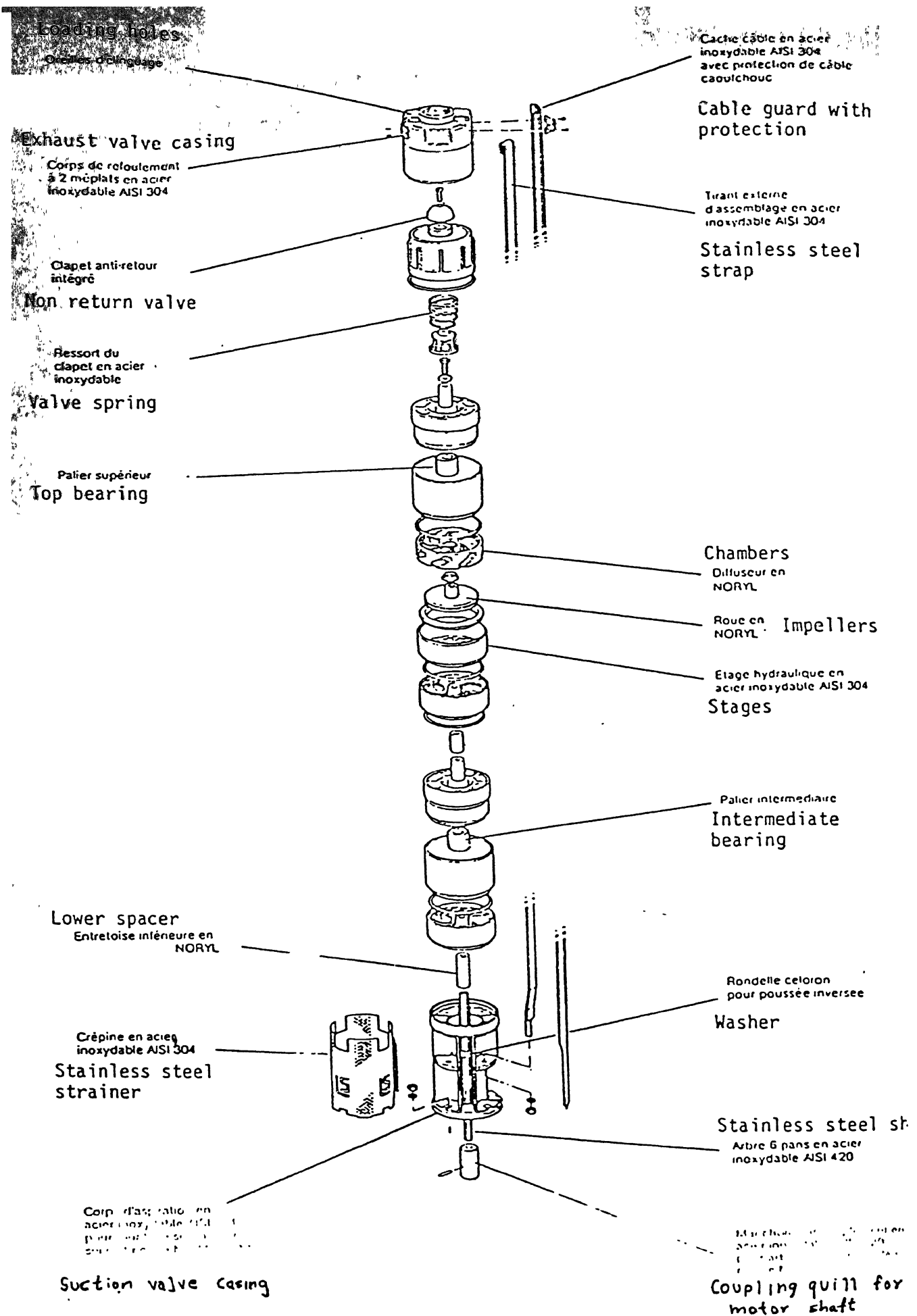


Fig. 3.10 : Submersible 4" multistage centrifugal pump

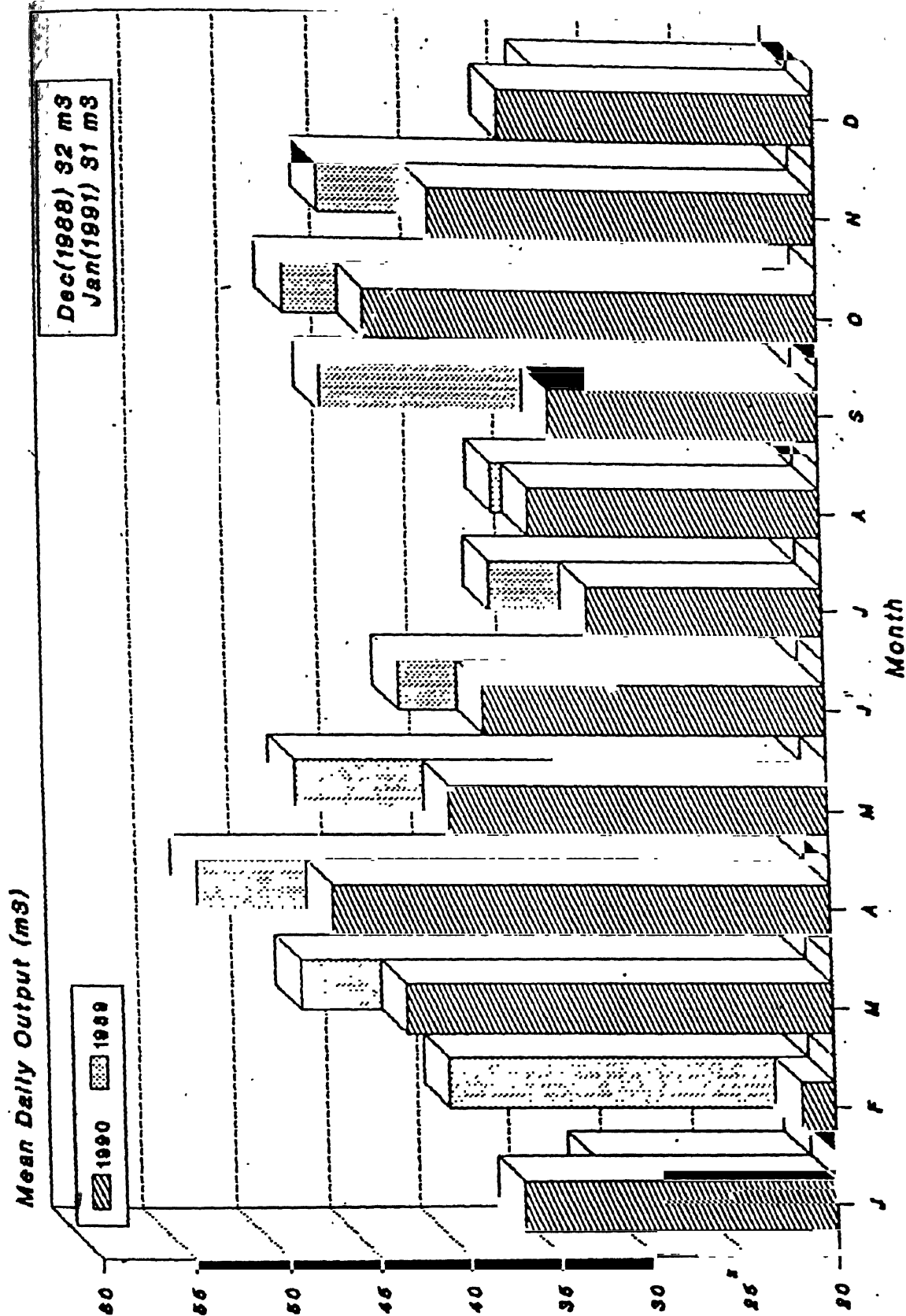
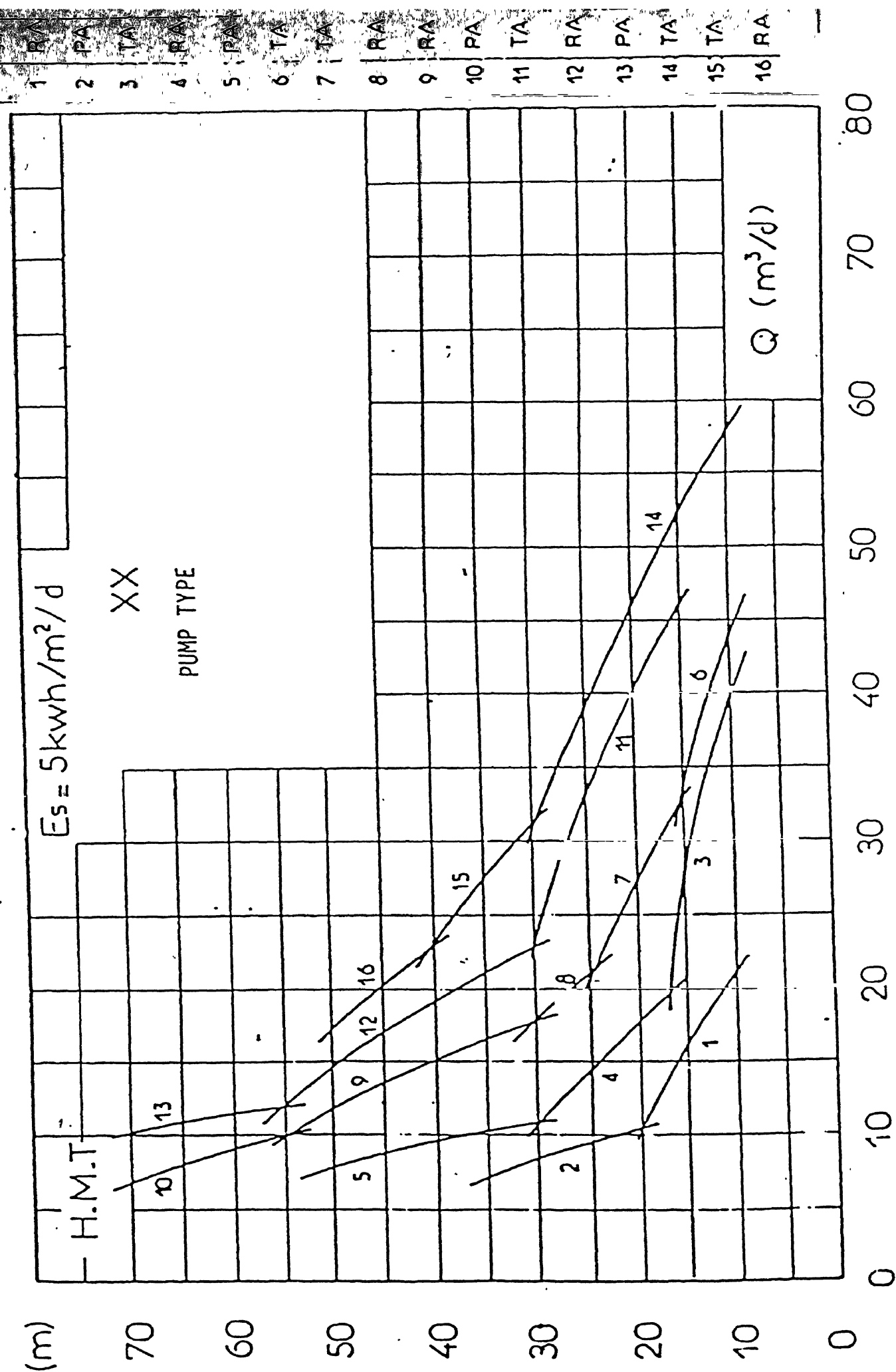


Fig. 3.12 : Gwal Pahari System Performance

SUBMERSIBLE 4" PUMPS



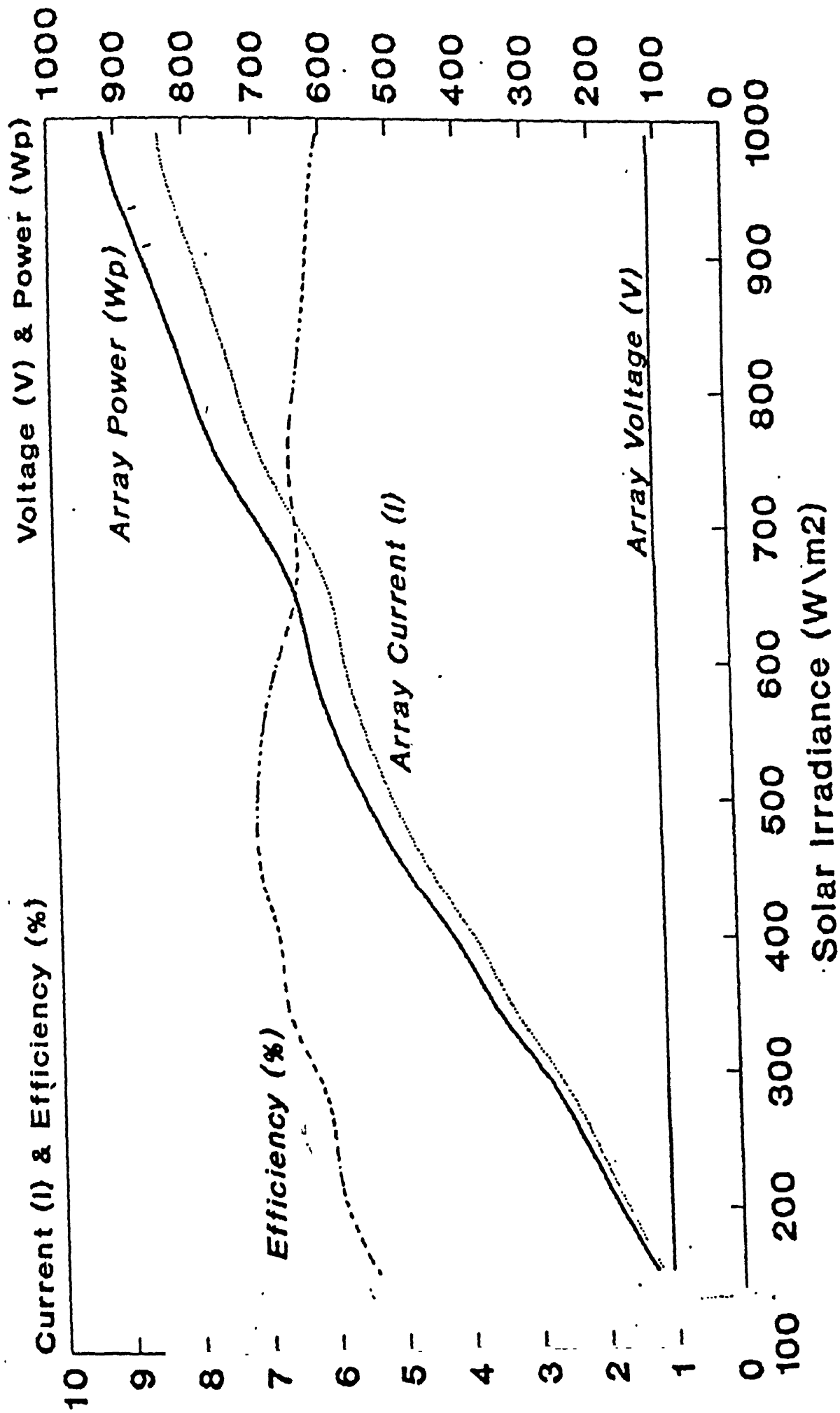
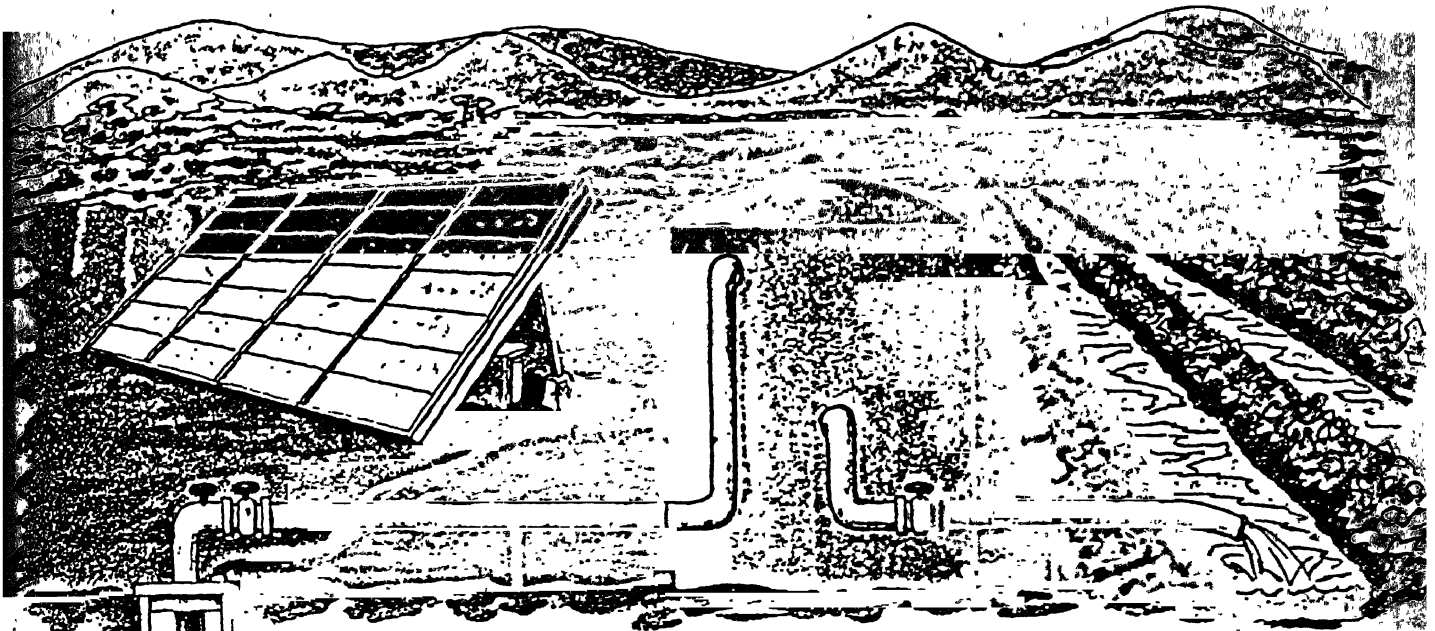


Fig. 3.14 : Array performance at Gual Pahar

Annexure - 1 A

Commercially available PV Pumping Systems



GRUNDFOS solar-powered deep well submersible pumping system

Sunlight and water are essential to all life on earth. GRUNDFOS has combined these two vital factors in an exceptional pumping system – GRUNDFOS' well-known submersible pumps driven by solar energy.

The sun is one of the largest sources of energy known to man. Every second it transforms 4.5 million tons of matter into light energy. The earth receives approximately 30 billion kWh/second, annually equivalent to more than 5 times the total energy resources on our planet.

GRUNDFOS is thinking of the future, and features like quality, high efficiency, reliability, and minimum operating costs are characteristic when talking about GRUNDFOS products.

These features are also key factors with the GRUNDFOS solar-powered pumping system.

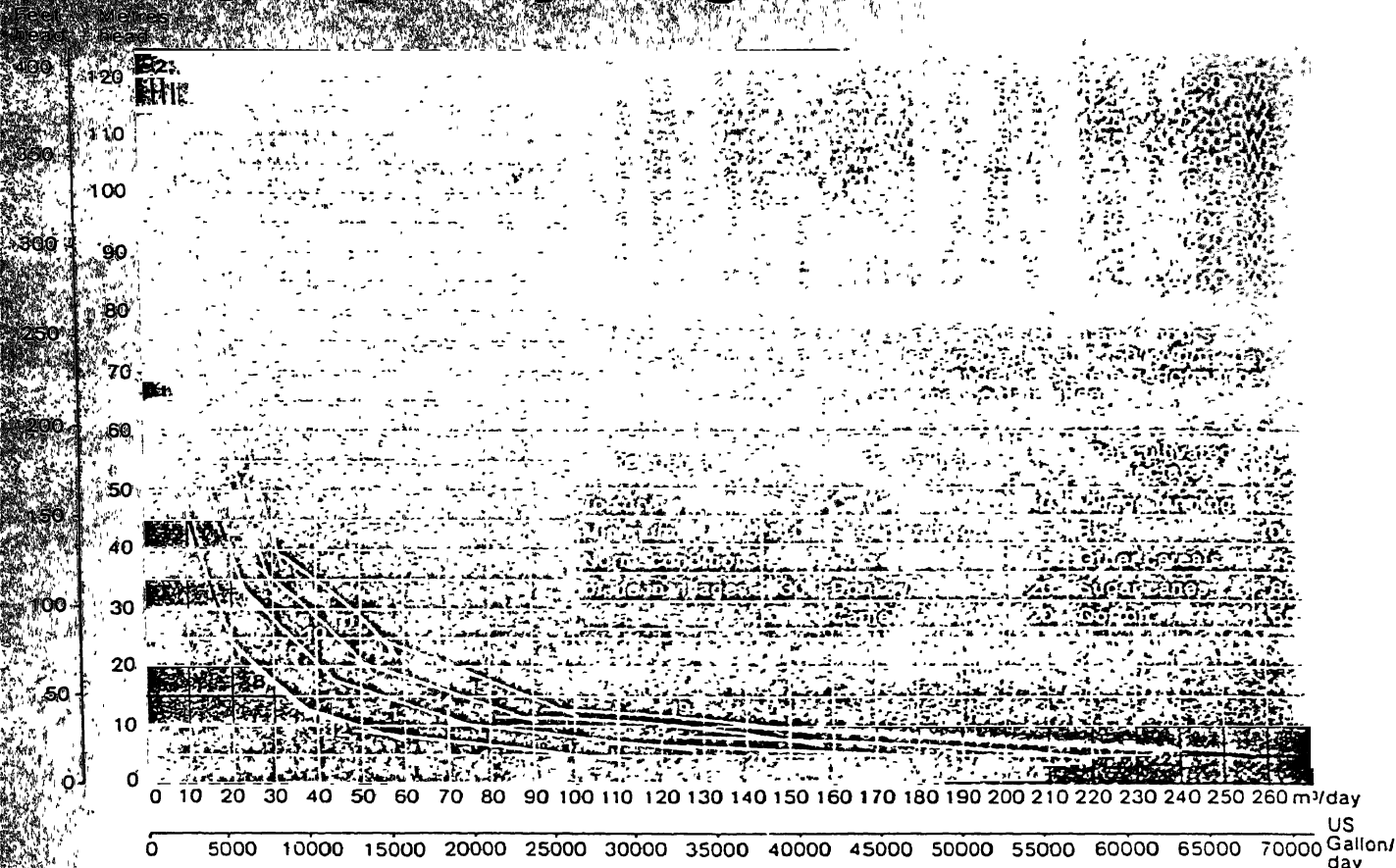
Applications

GRUNDFOS solar-powered pumping systems are specially designed to operate in areas where no reliable electricity supply is available. Solar energy is converted into electricity by photovoltaic solar panels. The solar energy is free and easily accessible to all. The process occurring in the solar panels is an entirely static process, and the only moving part in the whole system is the submersible motor/pump unit.

With this system, power bills and operating and maintenance costs are eliminated.

Photovoltaic solar pumping systems have many advantages. The most obvious one is that there is a natural relation between the availability of solar energy and the water requirement.

Survey capacity diagram



The above diagram shows the statistical water output per day during periods of peak sunlight.

Utilizing arrays of photovoltaic solar modules and a standard GRUNDFOS stainless steel deep well submersible motor/pump unit, the system produces up to 1.5 kilowatts of

electricity and is capable of pumping more than 230 m³ of water per day (60,000 gallons/day) during periods of peak irradiation and depending on the well parameters.

At lower quantities of water, the system is able to lift the water up to 120 metres (400 feet).

The standard range includes 22 system sizes.

Description of the system

The system consists of a few main components only:

- the solar array
- the DC-AC inverter
- the deep well submersible pump/motor unit

A system contains the number of solar modules which meets the power requirements of the actual system size.

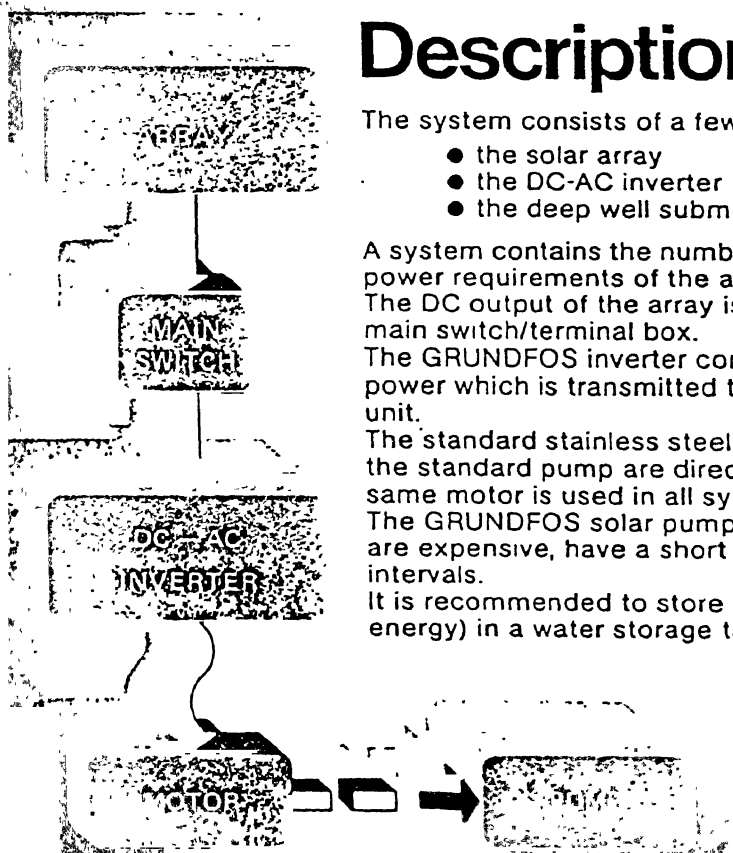
The DC output of the array is transmitted to the inverter through a main switch/terminal box.

The GRUNDFOS inverter converts the DC power into three-phase AC power which is transmitted to the deep well submersible pump/motor unit.

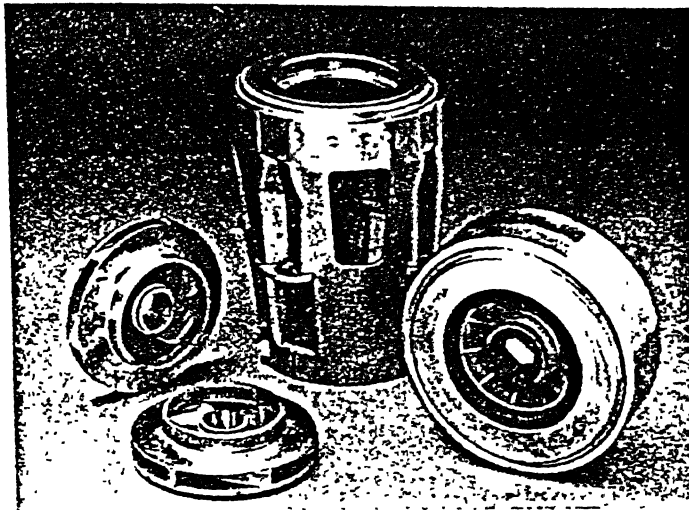
The standard stainless steel high-efficiency submersible motor and the standard pump are direct coupled and form a complete unit. The same motor is used in all systems.

The GRUNDFOS solar pumping system requires no batteries. Batteries are expensive, have a short life, and require maintenance at regular intervals.

It is recommended to store the pumped water (and thereby the energy) in a water storage tank or a reservoir.



GRUNDFOS submersible pumps entirely of stainless steel



Stage by stage, the components are assembled into a complete pump with suction interconnector and discharge chamber.

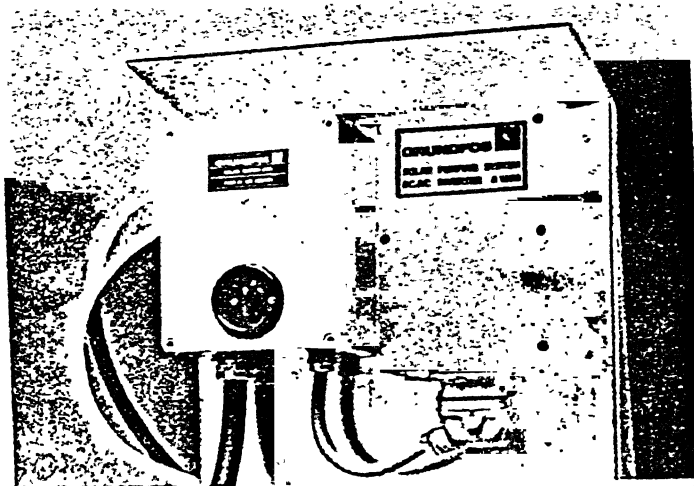
The GRUNDFOS motor, which forms an important part of the unit, has, from many years' experience in operation and production of submersible pumps, been developed and constructed for operation under extreme conditions.

The GRUNDFOS pump/motor unit offers the following advantages:

Throughout the world, GRUNDFOS submersible pumps have a reputation for maximum reliability as well as minimum maintenance and power consumption. Complicated individual parts are made from stainless steel plate correctly shaped and welded together to form complete impellers and intermediate chambers with guide vanes – the basic components in GRUNDFOS submersible pumps.

- Simple installation – threaded pump end for pipe-work connection and push-in cable plug and socket.
- Priming screw at suction interconnector protects against dry-running.
- Manufactured entirely from stainless steel.
- No supervision – pump and motor are water-lubricated.
- Low initial cost and low operating expenses.

DC-AC inverter Switch box-terminal box



The DC from the solar array is transmitted to the inverter through a main switch-terminal box.

The GRUNDFOS inverter converts the DC power produced by the ARCO SOLAR panels into a three-phase AC voltage to run the pump unit. It is a fully electronic, compact unit which incorporates the latest technology and meets the severest

demands for reliability, extremely long life, and high efficiency. The conversion of DC power into AC power is performed at an efficiency higher than 95%. The built-in control loops of the inverter ensure that all the power available from the solar panels is drawn continuously.

If the irradiation is intensified, the inverter will automatically increase the frequency and the voltage. As a result, the pump speed is increased.

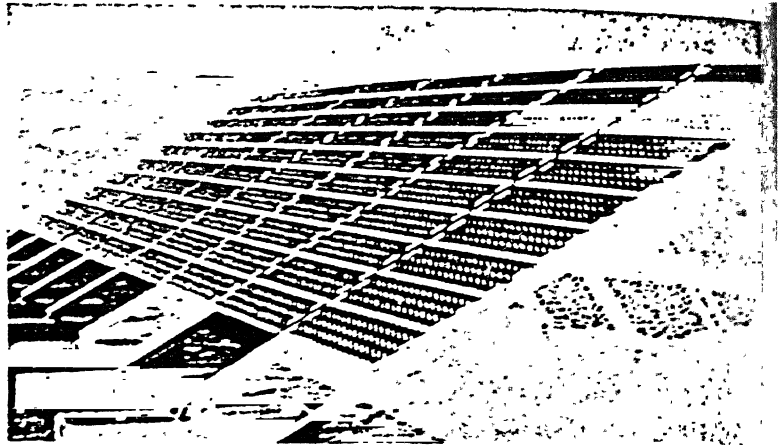
In practice, this means that the system is capable of delivering water even at very low irradiation values, e.g. immediately after sunrise or in cloudy periods.

Thanks to the automatic control system of the inverter, the available solar energy will all the time be utilized to its maximum. A maximum system efficiency thereby achieved.

The inverter is equipped with a multi-plate which makes it possible to fit/remove the inverter without disturbing the electrical connections.

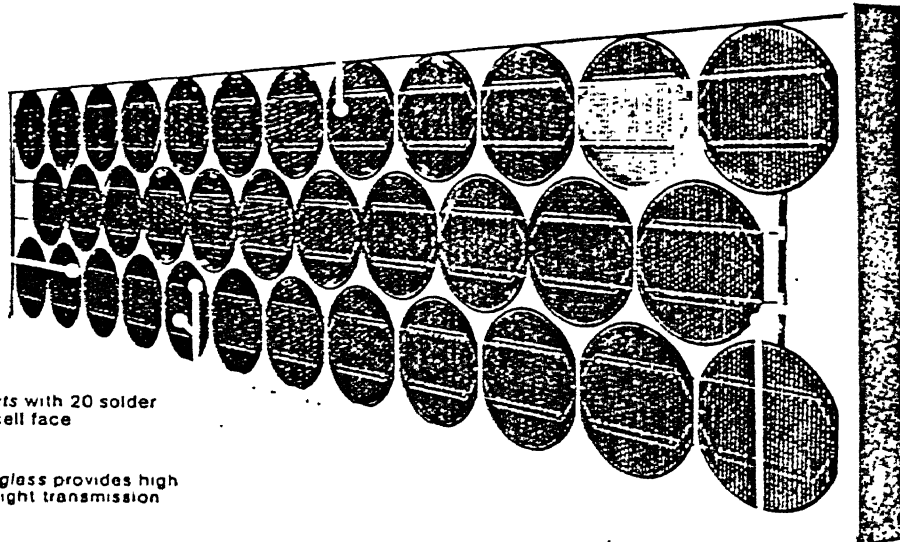
ARCO SOLAR array Free-standing DC generating station

To ensure a uniform high quality of the whole system, GRUNDFOS has chosen ARCO SOLAR's latest module M51, which is the very best solar panel in the market today. The subarray consists of 7 modules. Two, three, four, or five subarrays can be connected in parallel to meet the power requirements of the system in question. Both the modules and the supporting structure are robust and can stand every conceivable weather condition. The modules have been tested at wind velocities of up to 200 km/h.



Solar cells are approximately 4 inches in diameter, with each state-of-the-art single crystal unit producing more than 2 amps at 0.5 volts.

Texturized surface of each cell reduces energy loss due to reflection.



Multi-redundant contacts with 20 solder connections on each cell face

Water-white tempered glass provides high strength and superior light transmission characteristics

Aluminium side rails interlock for torsional strength and allow for fast and easy mounting.

Polymeric laminating material bonds the glass, cells and metal foil back surface together.

Computer calculations

The irradiation on a tilted surface in a given area on the earth is dependent on a number of factors such as geographic position, climatic conditions, atmospheric conditions, tilt angle, time of the year, etc.

Therefore, it is an extremely complex matter to calculate the irradiation in a given area at a given time. From statistical weather observation data, etc., we are today able to dimension a GRUNDFOS solar pumping system for use anywhere in the world by means of a large computer in GRUNDFOS' research centre.

GRUNDFOS has developed a complete design manual which permits a quick and simple selection of a GRUNDFOS solar pumping system, irrespective of the geographic position.



BUENA SERA



HERMES 2 solar pumping systems

I sistemi H2, appartenenti alla linea HERMES della Italsolar per il pompaggio di acqua, sono indipendenti da fonti energetiche esterne.

I sistemi H2 integrano ed ottimizzano unità di pompaggio con generatori fotovoltaici. Essi hanno "inter alia" le seguenti caratteristiche:

- Non producono fumi ed altri generi di inquinamento
- Sono adattabili ad ogni situazione ambientale e climatica
- Richiedono una minima manutenzione
- Hanno una elevatissima affidabilità
- Hanno consumi energetici contenuti

I sistemi H2 sono particolarmente idonei per la fornitura di acqua a case isolate e villaggi, per l'abbeveraggio di bestiame, per la fornitura di acqua per l'irrigazione e per molte altre applicazioni.

I sistemi H2 sono realizzati con componenti della massima affidabilità e vengono scelti in modo specifico per ogni singola applicazione.

La capacità dei sistemi H2 può essere facilmente incrementata qualora aumenti la richiesta di acqua.

I sistemi H2 sono disponibili nelle seguenti versioni:

- SISTEMI H2-SW, con pompe di superficie
- SISTEMI H2-BH, con pompe sommerse

I sistemi standard utilizzano generatori fotovoltaici costituiti da moduli della serie HM, della serie HP o della serie HA.

I sistemi H2 possono essere provvisti di uno stoccaggio di energia elettrica in batterie.

The Italsolar HERMES 2 systems-H2 for water pumping are independent from external energy sources. The H2 systems integrate and optimize pumping units with photovoltaic generators. They include "inter alia" the following features:

- No smoke, no pollution of any kind
- Adaptability to any kind of environmental and climatic conditions
- Very low maintenance requirements
- Very high reliability
- Very low energy consumption

The H2 systems are particularly suitable for water supply to remote houses and villages, for livestock watering, for irrigation water supply and for many other applications.

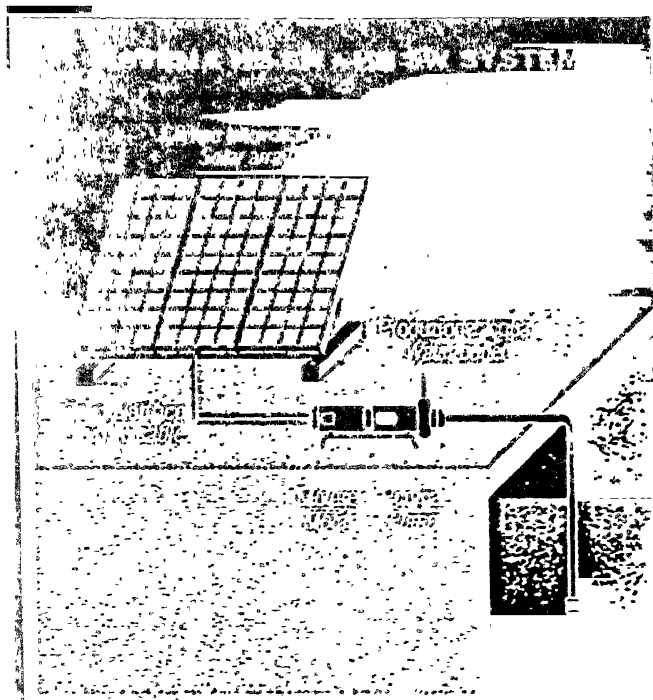
The H2 systems are made of very reliable components and chosen individually for each application. If the required amount of water increases, a H2 system capacity can easily be extended.

The H2 systems are available in the following versions:

- H2-SW systems, shallow well type
- H2-BH systems, borehole type

Standard systems use photovoltaic generators of the HM, HP or HA series. The H2 systems can be equipped with a battery energy storage.





PRINCIPALI CARATTERISTICHE DEL SISTEMA H2

I sistemi H2-SW sono costituiti dalle seguenti parti principali:

- Generatore fotovoltaico
- Motore in corrente continua
- Pompa

I sistemi H2-BH comprendono in più un inverter per la conversione della corrente continua, generata dal campo fotovoltaico, in corrente alternata, richiesta dal motore della pompa sommersa.

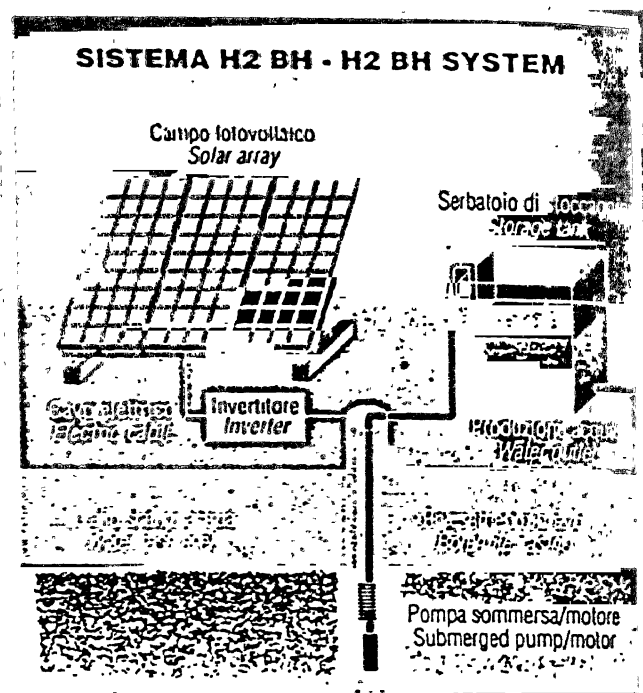
Gli inverter forniti dalla Italsolar sono compatibili con ogni pompa. L'utente in tal modo può scegliere idonee pompe disponibili localmente, evitando così problemi di parti di ricambio.

I sistemi H2-SW con pompe di superficie, sono idonei per quelle applicazioni ove sono richieste basse prevalenze. I sistemi H2-SW standard vanno da 250 Wp a 750 Wp.

I sistemi H2-BH, con pompe sommerse, sono idonei sia per basse prevalenze, sia per alte prevalenze. I sistemi H2-BH standard vanno da 0,75 kWp a 10 kWp.

Oltre ai sistemi H2 standard, la Italsolar può fornire sistemi specifici.

Il diagramma mostra le prestazioni di sei diversi sistemi H2-BH-1400 Wp, con una radiazione incidente di 6 kWh/m² giorno.



H2 SYSTEM MAIN FEATURES

The H2-SW systems are made of the following main parts:

- Photovoltaic generator
- DC motor
- Pump

The H2-BH systems also include an inverter to convert the DC-power generated by the solar array to AC-power required by the bore-hole pump motor. The inverters supplied by Italsolar are compatible with all pumps.

The user, therefore, can select appropriate locally available pumps and thus avoid spare parts problems. The H2-SW systems - shallow well type - are suitable for low head applications.

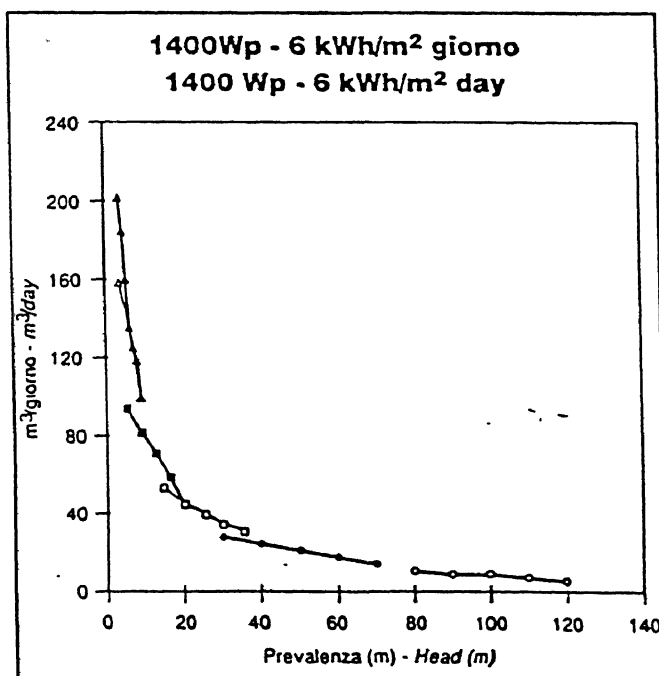
The H2-SW standard systems range in size from 250 Wp to 750 Wp.

The H2-BH systems - bore-hole type - are suitable for both low and high head applications.

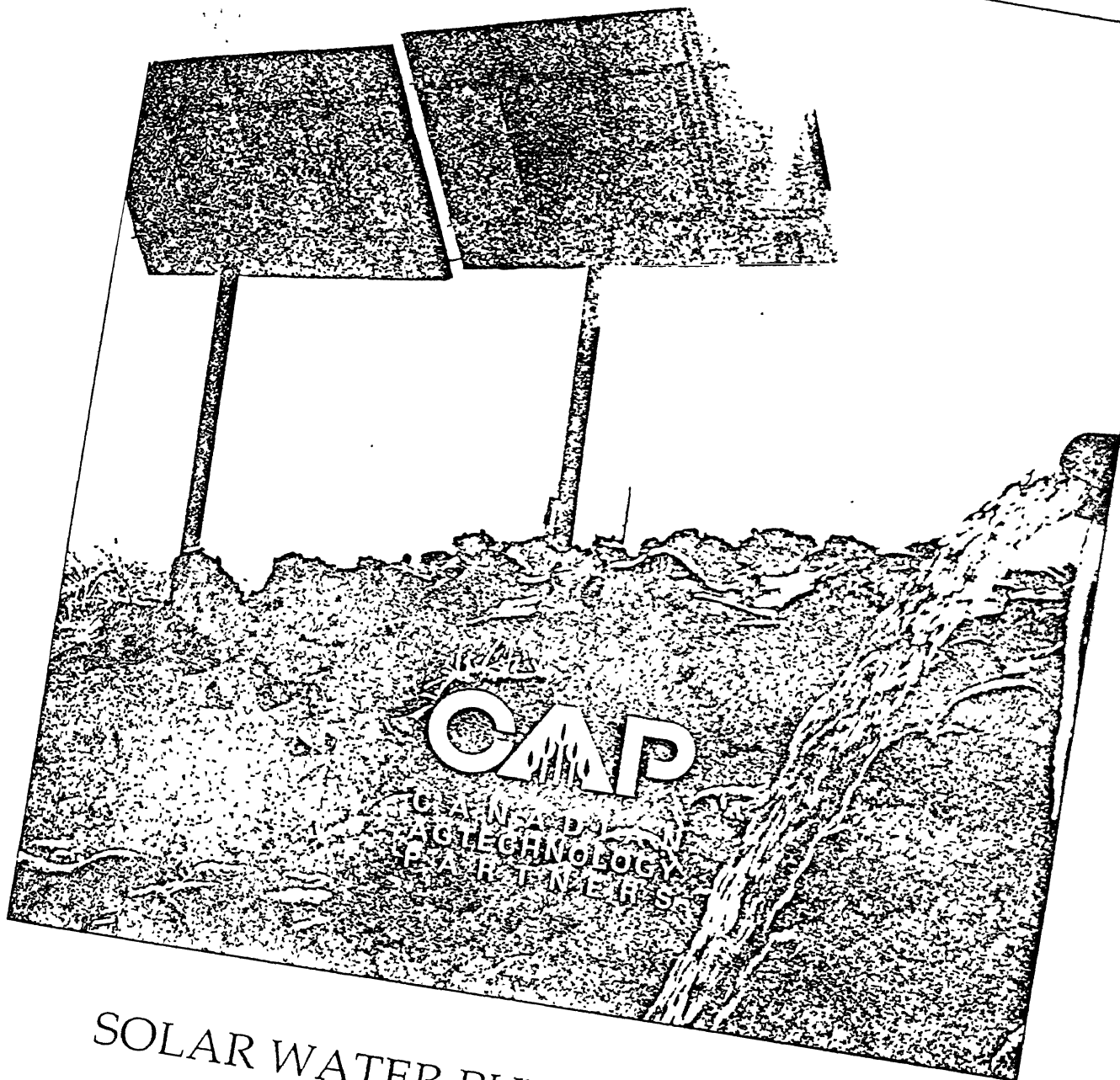
The H2-BH standard systems range in size from 0.75 kWp to 10 kWp.

Italsolar, in addition to standard H2 systems, can supply specific systems.

The diagram shows the performances of six different H2-BH systems - 1400 Wp, under an irradiation of 6 kWh/m² day.



Canadian Agtechnology Partners



SOLAR WATER PUMPING SYSTEMS

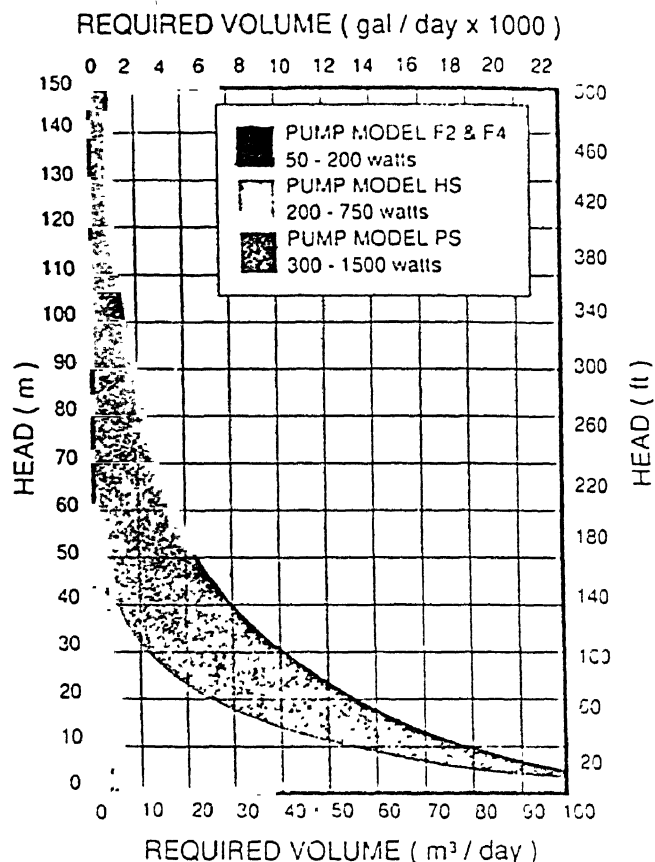
Solar Pump Selection

Three factors determine the design of a solar pumping system for a given application:

- 1) The average daily volume of water to be pumped.
- 2) The total pumping head.
- 3) Available hours of sunlight.

Figure 1 provides a comparison of the CAP solar pump models. To determine the pump model most suitable for an application, reference the required volume (horizontal axis) and head requirement (vertical axis) to find the model category.

Design of the complete solar pumping system is done separately for each project to ensure that all of the site variables are considered. CAP utilizes a computer program with worldwide records of solar radiation data which allows the company to provide a system design and costs for various alternatives.



Shipping

The complete solar pump systems are light and compact. Delivery of the complete unit is economical, even by air freight.



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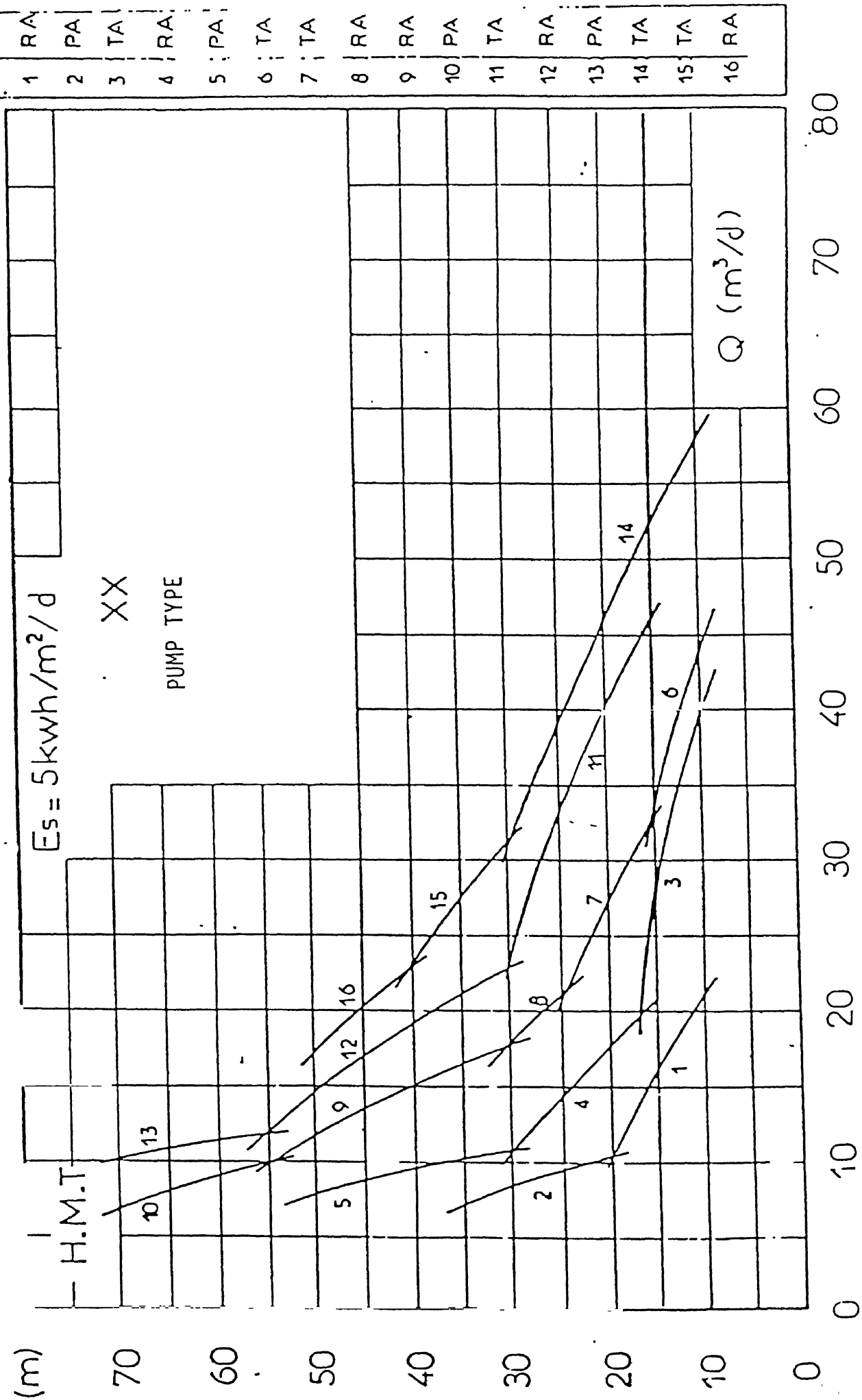
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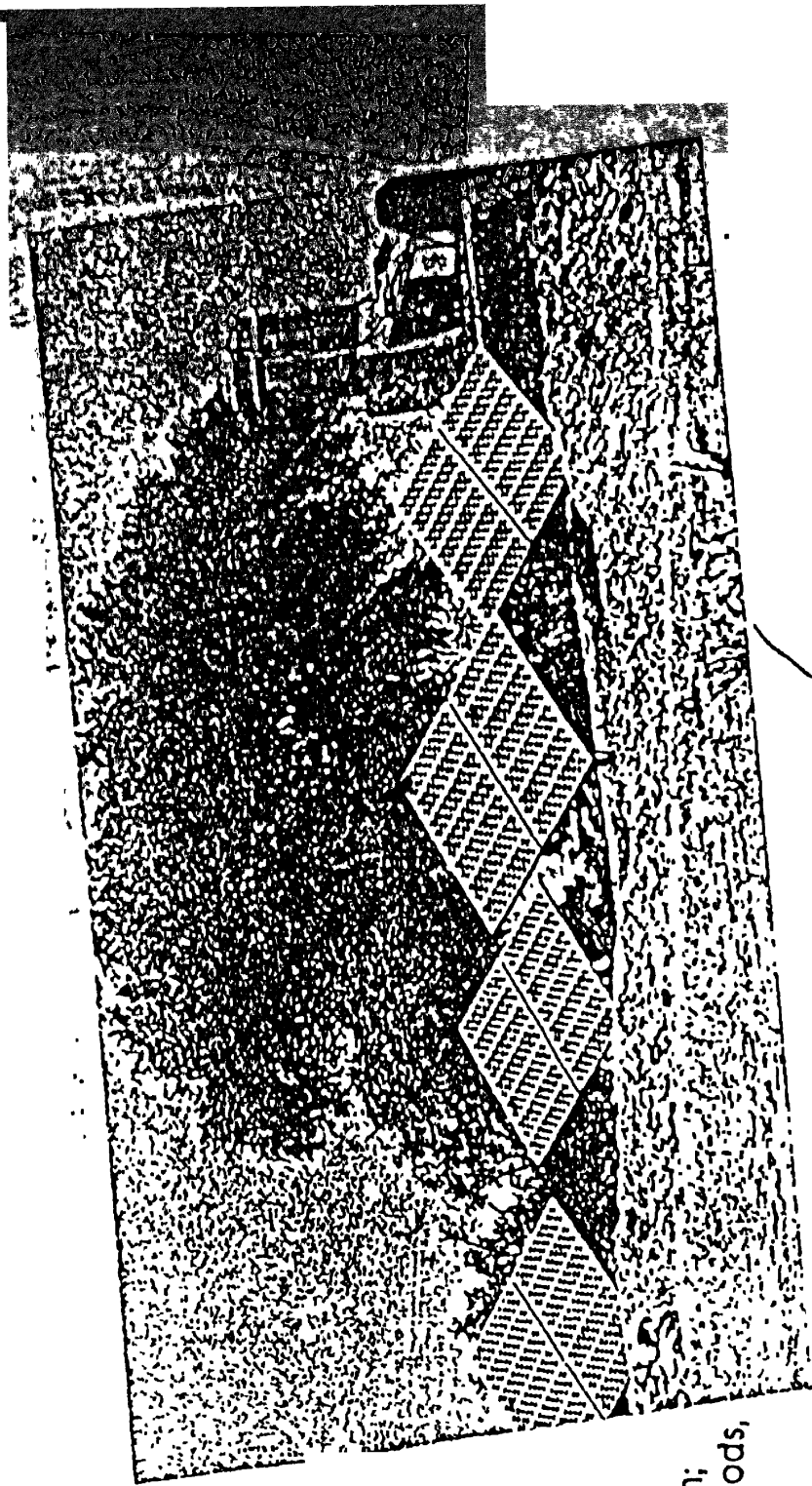
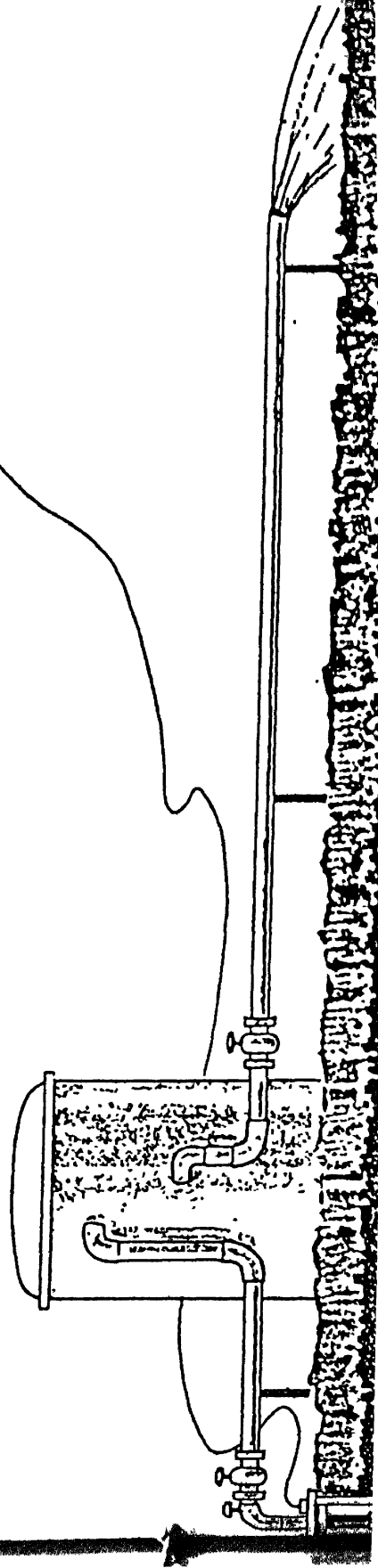
PHOTOWATT
INTERNATIONALS A

32 SOLAR MODULE SUBMERSIBLE PUMP

SUBMERSIBLE 4" PUMPS



Emerging up above the dark,
toward the higher light we turn;
We have attained the God of Gods,
The Sun itself, the highest light.



SOLAR PHOTOVOLTAIC DEEP WELL WATER PUMPING SYSTEMS



SOLAR POWERED PUMP CHARACTERISTICS

HEAD-DISCHARGE

CHART-A

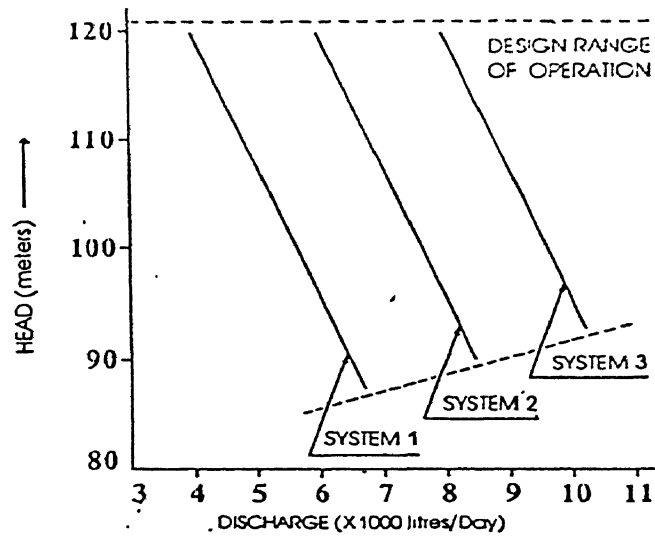


CHART-B

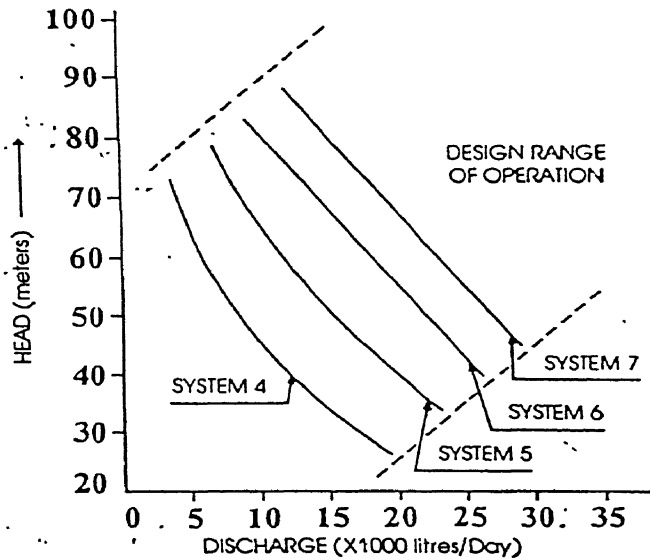
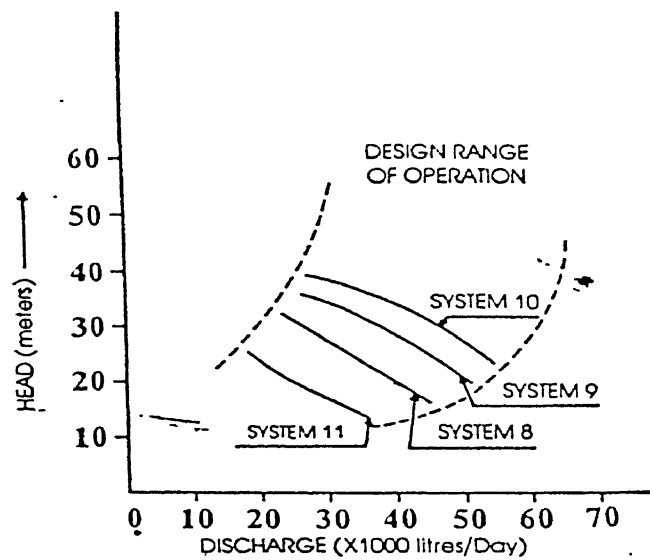


CHART-C



Note: Actual discharge will vary +10% to -20% with respect to typical figure read from chart.



CENTRAL ELECTRONICS LIMITED

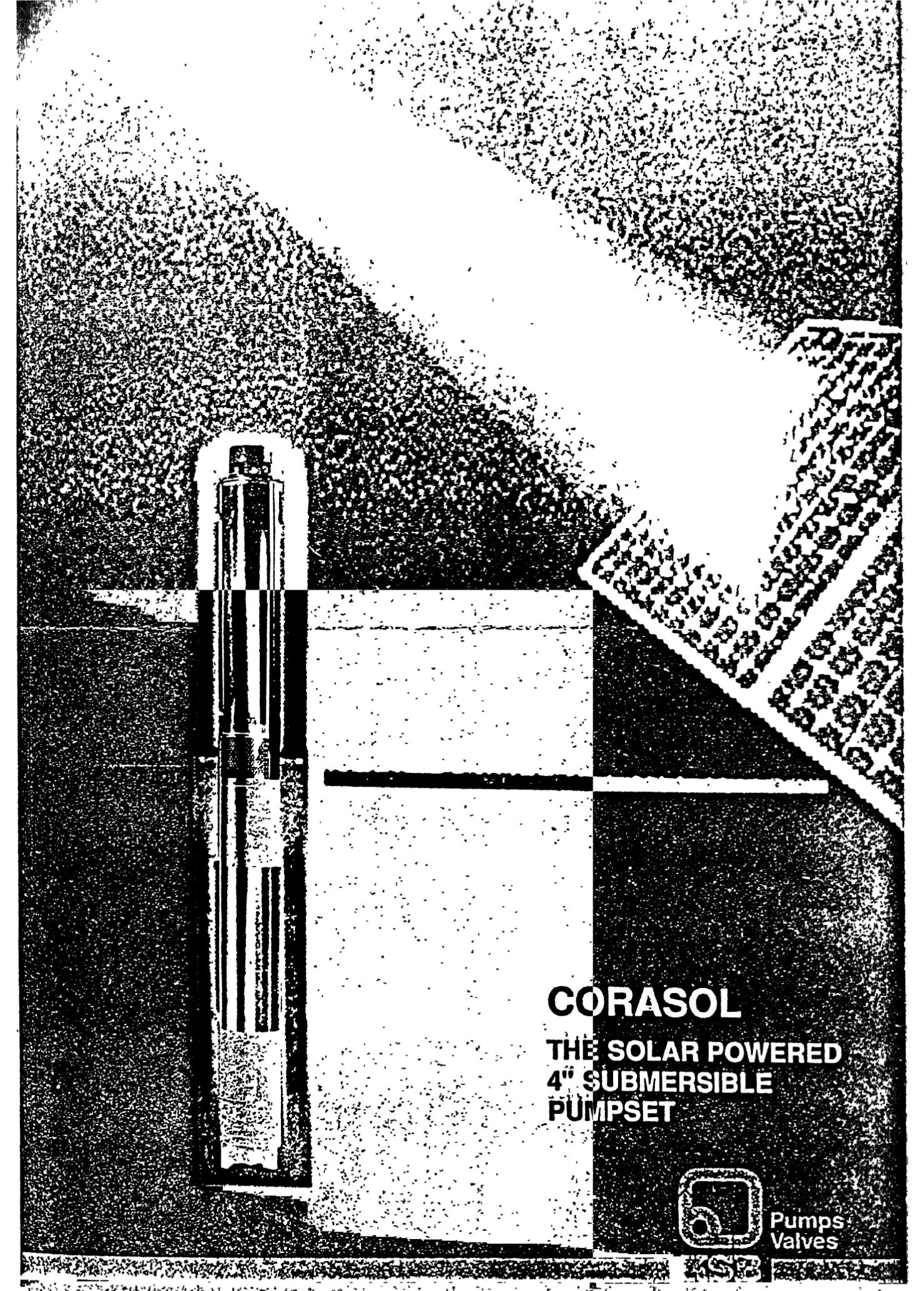
(A Public Sector Enterprise)

4, Industrial Area, Sahibabad-201 010 (U.P.), India

Phones: 861065 (Mkg), 860257 (Works), 526836 (Delhi Sales Office), 585657 (Regd. Office)

Cable: CELFERCORE-GHAZIABAD

Telex: 0592-203 CEL IN (Mkg & Works), 031-66945 CEL IN (Regd. Office).



CORASOL
THE SOLAR POWERED
4" SUBMERSIBLE
PUMPSET



Pumps
Valves

KSB

SPECIAL FEATURES:

The only 4" Submersible Pumpset with a new rewindable, water cooled, water lubricated motor, eliminating the possibility of overheating and withstands wide voltage fluctuations.

Stainless steel and high grade engineering plastic components resist corrosion and abrasion.

High grade engineering plastic components ensure smoother surface finish and precise geometry for better hydraulics resulting in high operating efficiency.

Conventional submersible pumps are oil lubricated whereas the CORA 100 is water lubricated reducing the chances of water contamination.

High operating efficiency.

Modular design concept results in higher interchangeability, easier availability of spares leading to low inventory.

Light in weight, easy to install.

Self priming due to submerged installation.

Can be used horizontally.

Noise free operation

APPLICATIONS :

Community water supply, irrigation of fields/farms, drip irrigation, seed farms, nurseries, dairies, stud farms, piggeries, high rise buildings, small scale industries, housing complexes, bungalows, fire fighting.

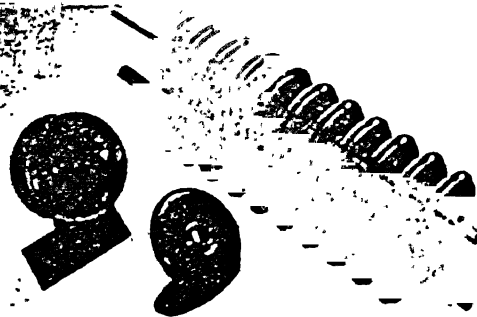
Diffuser
Impeller

Stainless Steel
Pump jacket

Rotor

Stainless Steel
Stator Pipe

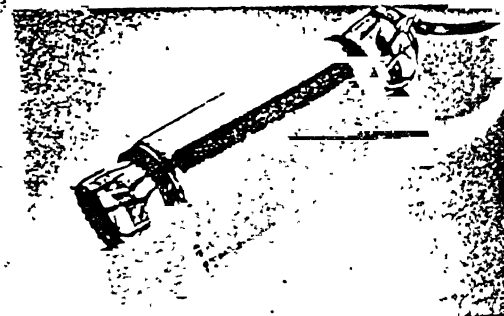
Mitchell-type
Thrust Bearing



Impellers, diffusers and stage casings made of engineering plastic for high corrosion resistance. Accelerated simulation tests with up to 10,000 ppm sand content in water have clearly shown much better service life than bronze or stainless steel. *

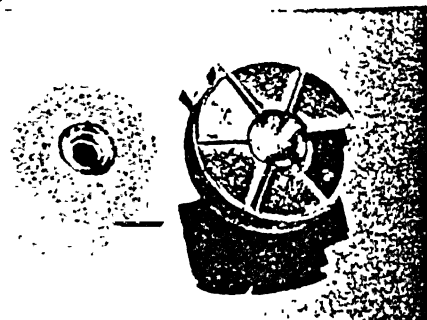
* Actual test results available on request.

Fully rewindable stator with special PVC insulated winding wire, with overhung ends for better heat dissipation.



OPERATING RANGE

Capacities	Q up to 11 m ³ /h (3 l/s)
Heads	H up to 160 m
Temperature of pumped medium	up to + 35°C
Motor	3 Phase



Mitchell type thrust bearing with tilting pad assembly, absorbs axial thrust under all adverse conditions

Annexure 2 A

Proposal for Installation of a PV Deepwell
water Pumping System

'Information about Site'

1. Name of the Organisation:
2. Contact Person(s) :
3. Full Postal Address for Communication
4. Telegraphic Address/
Telephone No./Telex
5. Proposed site for Installation
 - a) Exact Location/village :
 - b) Tehsil/
 - c) District
 - d) State
6. Modes of transport for approaching the site : Rail(Bus)/Taxi/Tempo/Rickshaw/
others(Specy)
7. Nearest Railway Station :
8. Site Details :
 - i) Approximate Human Population :
 - ii) Approximate No. of Cattleheads

Is the site electrified : Yes/No
8. Climatic conditions of the site
 - Max. Temp. °C
 - Min. Temp. °C
9. Water Table

Summer	<u>Metre</u>
Winter	<u>Metre</u>
10. Average Quantity of water Required daily on the basis of 40 lpcd for human and cattle population
11. Does a borewell/openwell exist at site where the proposed PV pump will be installed Yes/No

Contd.....2/-

12. If yes, Diameter of the well/borewell : Metre
13. Technical support/manpower available for Installation operation and Maintenance of the system Yes/No
14. Whether your organisation will be
- (a) willing to undertake the jobs of
- 1) Digging a proper borewell (if does not exist already),
- ii) Site preparation for installation of PV Array and pump.
- (iii) Fencing of the site
- iv) Storage tank required for the installation of the system and Yes/No
- (b) meet the required expenses Yes/No
15. Any other Information, you feel will be useful

Signature _____

Name _____

Designation _____

Organisation _____

Date _____

Annexure 2 B

Workshop Material

Two-Day Workshop
on

SOLAR PHOTOVOLTAIC PUMPING SYSTEM

21-22 December 1988

Tata Energy Research Institute
7 Jor Bagh New Delhi 110003

ATR ENERGY RESEARCH AND DEVELOPMENT
TWO-DEGREE
SOLAR PHOTOVOLTAIC
RESEARCH AND DEVELOPMENT
DEPT. OF ENERGY
WASHINGTON, D.C. 20545
1988

YOUR SPV PUMPING SYSTEM consists of
three (3) major subsystems

Solar Photovoltaic Array

(Modules, Panel Structures and
Electrical Connection Accessories)


dc-to ac Inverter

The Pumping Unit


(Submersible 4-inch motor-pump set)

HOW DOES YOUR PUMP WORK ?

First, Sunlight is converted to
DC electricity by the SPV Array



*The DC electricity is then converted to
AC electricity by the Inverter*



The AC electricity drives the Motor
of the Pumping Unit

Pumped Water varies as Sunlight changes

The Solar Photovoltaic (SPV) Array generates electricity as long as sunlight is incident on the Array.

It can produce only dc electricity. The amount of electricity produced depends on the amount of incident sunlight. Hence, the output power varies all day long.

The INVERTER converts the dc electricity to ac electricity to run the pump.

It also ensures that most efficient operation of the SPV Array is maintained irrespective of the amount of sunlight available.

The Pumping Unit lifts water from the

There are 32 SPV Modules. Each module is of 40 Wp capacity. Thus, the total capacity of the Array is 1,280 Wp, when measured under Standard Test conditions (STC)

FOUR (4) modules are to be SERIES connected and mounted on one PANEL structure.

Two (2) PANELs are to be SERIES connected side by side. There will be four (4) such SERIES connected sets of PANELs. These four (4) will be connected in PARALLEL to form the SPV ARRAY.

Thus, there will be four strings of eight (8) series-connected modules, which will be connected in parallel to form the SPV Array.

SOME IMPORTANT POINTS TO REMEMBER

1. Try to avoid a grassy or green land for installing the SPV Array.
2. Ensure that there are no trees or tall structures at or near the site where the array is to be installed.
3. Ensure that the array surface faces due SOUTH. You can determine due south at your site either by using a Compass or using the method given in the Notes.
4. Keep the distances between the Array and the Inverter, and the Inverter and the Pumping Unit, small.

Solar Photovoltaic Pumping Systems are expensive. Therefore, some precautions should be taken to ensure maximum use and minimum wastage of energy.

- 1. Keep electrical distances small.**
- 2. Try to keep the TOTAL PUMPING HEAD as near to 20 metres as possible.**
- 3. Keep the bends on the piping as smooth as possible.**
- 4. Keep the Array surface clean. It is advisable to clean the surface once a week.**
- 5. Ensure that electrical connections are properly and correctly made.**
- 6. Do not cast shadow on array surface.**

Please remember that SPV electricity is presently expensive.

Hence, use it as much as you can.

Let the pump run all throughout the day.

Switch it ON early morning.

Switch it OFF when the sun sets.

Let the water be pumped throughout the sunlight period.

Two-day Workshop on
Solar Photovoltaic Pumping System
21 and 22 December 1988

Technical Notes
on
SPV Pumping System

Tata Energy Research Institute
7 Jor Bagh
New Delhi 110003

Solid-State Reliability of Solar Photovoltaics

A technical understanding of Solar Photovoltaics (SPV) involves the knowledge of sophisticated physics, chemistry, statistical sciences and various branches of engineering. It is not at all necessary for you, the users of the SPV Pumping Systems, to understand any such intricate feature. However, it will help if you appreciate at least some of its important aspects. Let us first enumerate some of these features.

One important feature of the SPV Pumping System that you are going to use is that it has solid-state semiconductor devices -- SOLAR CELLS -- generating the electrical energy from sunlight. In this regard this pumping system is unique. It cannot be compared with any conventional electrical pumping system that you may have handled earlier.

A conventional electrical pumping system works on electrical energy, supplied either by the transmission lines or by a diesel generator. A standard electricity generator has a mechanically moving turbine, which runs on energy obtained from the burning of either coal or diesel oil. In contrast, the SPV energy source supplying electricity to the motor-pump set does not have any moving part. This feature results in the highly desirable solid-state reliability of the SPV pumping system.

The importance and advantages of solid-state reliability can be judged by comparing the currently-used transistorised radio receivers (commonly known in India as the "TRANSISTOR") with the outdated valve radios, which were in use during the forties and fifties. You know that a "transistor" rarely goes bad with a much superior performance compared to the outdated valve radios. Similarly, a properly designed SPV pumping system should work for ages without failure, due to its solid-state reliability.

Solar Cells

The heart of your SPV pumping system is the Solar Cell. The solar cell is made of silicon. The solar cell converts the incident sunlight directly into dc electricity. As long as sunlight is incident on the exposed surface of a solar cell, a fraction of that light is converted directly into electricity.

The magnitude of the converted electrical energy and the energy conversion efficiency depend on various operating parameters, such as the intensity and spectral distribution of the INCIDENT SOLAR radiation (INSOLATION), solar-cell operating temperature, magnitude of the externally connected load (that is, the pumping unit or the motor-pump set), etc.

The active surface area of a solar cell has no effect on the voltage generated by a solar cell. There are two important voltages defined for a solar cell. The open circuit voltage is the voltage measured at the output of a solar cell when there is no load connected across it. This open-circuit voltage is approximately 0.6 volt. However, the solar cell will operate most efficiently at about .45 - .50 volt only. This is referred as the peak-power point voltage.

Both these voltages depend critically on the temperature. The dependence is on the solar-cell operating temperature and not on the air temperature. The solar cell operating temperature is usually 20 to 25 degrees Celsius higher than the air temperature. They decrease as the solar-cell operating temperature increases.

Similarly, two different currents are defined for a solar cell. The short-circuit current is the current through an ammeter when it is connected directly across the output terminals of a solar cell. The Peak-Power Point current is the current output from a solar cell when it is operating at the most efficient conditions. Both these short-circuit and peak-power point currents are linearly proportional to the active area of the solar cell and the intensity of the incident sunlight. Both the currents increase marginally if the solar-cell

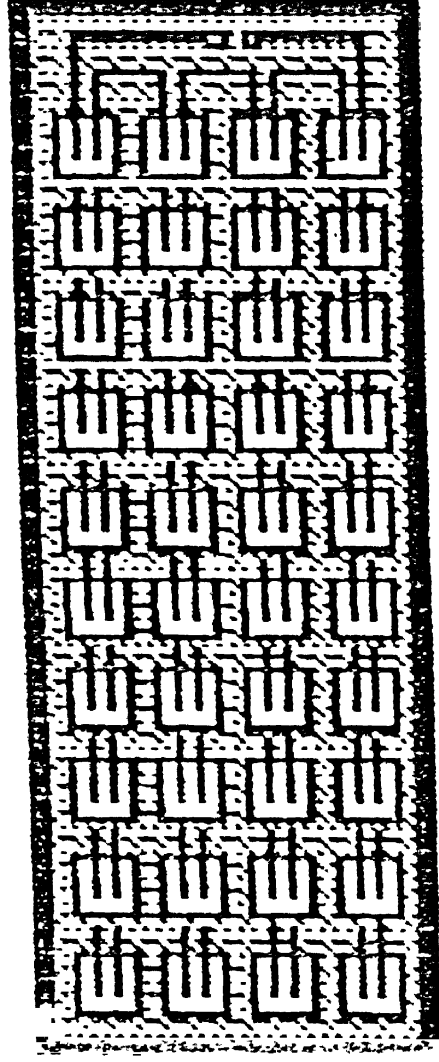
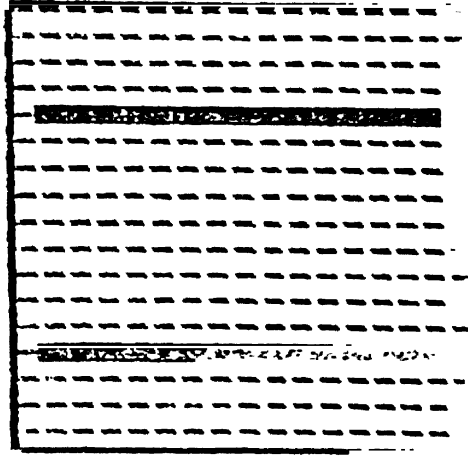
operating temperature increases.

The Peak-Power output of a solar cell is the product of its peak-power point voltage and the peak-power point current. It is the maximum electrical power that the solar cell can deliver at the specified test conditions. It depends on the conversion efficiency of the solar cell. The approximate magnitude of the peak power of a 12.5 percent efficiency and 100 mm diameter solar cell, at the STANDARD TEST CONDITIONS (STC), is only one peak watt (Wp). The peak power strongly depends on the sunlight intensity and the solar cell operating temperature. It decreases by 0.4 to 0.5 percent per degree Celsius rise in the cell-operating temperature.

Modules, Panels and Arrays

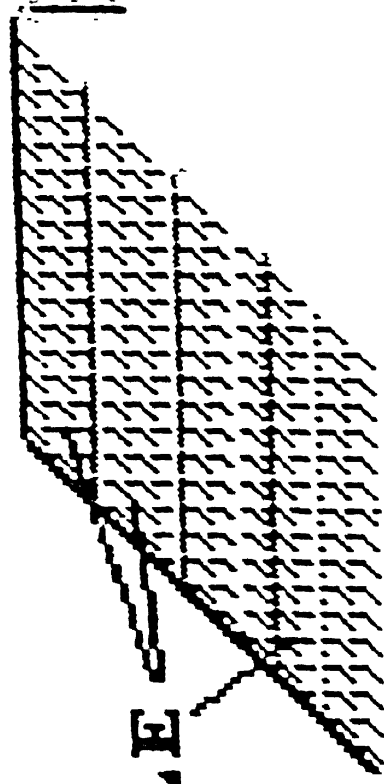
In order to generate a reasonable amount of power at a workable voltage, a pre-selected number of solar cells are interconnected in a series combination. This interconnected string of solar cells is then hermetically sealed with a transparent and tempered front glass cover to form the **SPV Module**. Modules form the basic building blocks of all SPV Pumping Systems.

Technical parameters similar to those for solar cells are also defined for the SPV modules.



SOLAR CELL

SPV MODULE



**SPV
MODULE**

***Four modules
are connected
in series to
form a panel***

SPV PANEL

Your SPV Pumping System has a total of 32 (thirty two) SPV Modules. The solar cells used in these modules are made of multi-crystalline silicon. Each module contains 40 cells in series connection. Each cell gives approximately 1 Wp of peak power output at STC. Therefore, the peak-power output of each module under the standard test conditions is approximately 40 Wp. However, since both the solar intensity and the solar-cell operating temperature vary all throughout the day, the peak-power output of each module may vary from 0 Wp (at complete darkness) to a maximum of 40 Wp.

A selected number of SPV modules themselves have to be interconnected to form the SPV Panel. The selected number of modules are interconnected and put up on a metal frame structure to form a Panel. Your pumping system contains 8 (eight) Panels, each containing 4 modules connected in series. Thus, you have components for a total of 8 metal frame structures which would form the 8 panels required to operate the SPV pumping system.

In the SERIES connection of the 4 modules to form a Panel, the POSITIVE terminal of the first module is connected to the NEGATIVE terminal of the next module. The positive terminal of this second module is then connected to the negative terminal of the third module. This procedure is repeated for all the 4 modules to form the panel. The NEGATIVE terminal of the first module and

the POSITIVE terminal of the 4th. module become the negative and positive terminals of the panel. These terminals are taken out for further connection later.

The Panels must then be suitably interconnected in the field. A selected number of SPV Panels, when interconnected in the required fashion, forms the SPV Array. The 8 panels of your SPV Pumping System will also make the Array. The interconnection detail. of your pumping system is as follows:

1. Two (2) panels will be connected in series. The 8 panels will thus form 4 (four) sets of series-connected panels.
2. These 4 sets of series-ⁿconnected panels are then to be connected in parallel to form the Array.

The series connections between two panels are to be done exactly the same way as those between the modules. This procedure was explained above. For the parallel connections amongst the 4 sets of series-connected panels, the following methodology has to be followed: All the POSITIVE terminals of the 4 sets of series-connected Panels are to be connected together. Separately, all the NEGATIVE terminals are to be connected together. These two common terminals will form

The positive and negative terminals of the complete SPV Array. These two terminals will be connected to the INVERTER input of your Pumping System.

Balance-of-System

Apart from the motor-pump set and the SPV modules, panels and array, you would also require a suitable control electronics, for the efficient operation of your motor-pump set. Such subsystems are together known as the Balance-of-System (BOS). The nature, type and quantities to be used of BOS are dependent on the desired functions of the SPV energy systems. In your case, the BOS consists of only one dc-to-ac electronic inverter.

As we have noted earlier, the solar cells and modules produce dc electricity. Hence, it could only drive a dc motor-pump set. However, dc motor-pump sets are not very efficient. Therefore, ac motor-pump sets are generally used in SPV pumping systems. In order to use an ac motor-pump set, one has to convert the generated dc electricity to ac electricity. This would require a dc-to-ac INVERTER. The Inverter not only converts the generated dc energy to ac electricity, it also ensures that the maximum amount of generated electricity is efficiently used by the motor-pump set.

As far as we are concerned here, the Inverter is a "black-box". The output from the SPV Array is to be connected to the input of the Inverter, and the output from the Inverter is to be connected to the terminals of the Motor of the motor-pump set. However, one must remember that the output from the Inverter is not the same as the conventional 220 volts 50 cycles ac electricity that we normally use. Therefore, taking out the motor-pump set and connecting another load (like another motor or bulb or fan) will not work. In fact, this may damage the Inverter.

Pumping Unit

Your pumping unit consists of a highly efficient 4-inch (100 mm) submersible motor-pump set, which operates on ac electricity at variable frequency from 0 to 60 cycles per second (Hz). This pumping unit is designed to be installed in a bore-well of 4-inch diameter. It can also be installed in an open well, provided suitable precautions are taken.

The pumping unit has been designed to operate at its maximum efficiency when the TOTAL PUMPING HEAD is 20 (twenty) metres. The Total Pumping Head consists of the physical head of the water table from the water delivery point plus the frictional losses in the piping. If bends are used in the piping, that would introduce further

losses, and hence, further head. As a rule of thumb, every 10 (ten) metres of GI piping introduces approximately 1 (one) metre of vertical HEAD.

You should ensure that the TOTAL PUMPING HEAD in your system should be 20 metres with a tolerance not exceeding 2 metres on either side. If the Total Head differs too much from this figure, then the water output will be reduced substantially.

Further to reduce the wastage of expensive energy, you must also ensure that the bends used in the piping, if any, should have gradual bends and not sharp bends. Gradual bends introduce less resistance to water delivery.

Some Features of SPV Pumping System

There are some features specific to solar photovoltaics in general, and SPV pumping system in particular. Many of these features may appear novel to the users of traditional forms of electrical systems. Some of these features are summarized below:

*** An SPV array produces direct-current (dc) electricity. You would require ds-to-ac inverters to convert the dc electricity to the more conventional ac electricity.

*** The array is neither a constant-voltage source nor a constant-current source.

*** The output and performance of the array strongly depend on many climatic and environmental factors. They also depend on the magnitude of the load.

*** The array performance depends on the homogeneity of sunlight illumination on the solar cell surfaces. Shadowing of the front surfaces of the modules not only reduces the electricity produced but also would likely to damage the solar cells and modules.

*** The SPV system performance depends on the angle at which the sunlight is incident on its surface. It also depends for a fixed array on the angle at which the array is installed with respect to the horizontal. If this angle is varied in a planned manner once in one or two months, the SPV system would work more efficiently.

It is recommended that the SPV Array be kept at a constant angle, if facilities are not available to orientate the array once every two months. The angle that your array would have to subtend to the horizon would

vary from place to place. The following is a suggestive listing of the fixed angle that the array should subtend with the horizontal surface:

for Arunachal Pradesh	::	15-20 degrees.
for Tripura	::	15-20 degrees.
for Bihar	::	10-15 degrees.
for Orissa	::	10-15 degrees.
for Rajasthan	::	20-25 degrees.
for Gujarat	::	15-20 degrees.
for Maharashtra	::	15-20 degrees.

These are approximate figures, which should be checked during the field work.

If facilities are available to orient the array once in every two or three months. then the following general methodology may be followed::

The angle should be more during winter and less during summer and monsoon months. For example, during the months of November, December and January, the angle may be approximately the sum of the local latitude and 23 degrees. Thus for a place having a latitude of 20 degrees, the angle during these

three months may be between 40 and 45 degrees. On the other hand, the angle during May, June and July may be near to 5 or 10 degrees only. The SPV pumping system will give more water if this orientation at intervals of two or three months are carried out.

*** SPV arrays can only convert sunlight into electrical energy across a connected load. It cannot store that energy. For storing the generated electrical energy, one will have to use storage batteries.

*** Unlike standard turbine generators, SPV energy sources can generate electricity only during the sunshine hours. Therefore, your SPV pumping system will pump water only as long as enough sunlight is incident on the array surface. Any shadowing will reduce the output water. ^hShadowing of even one single module may reduce the water output substantially.

Major Advantages of SPV

Finally, let us enumerate some of the major advantages of solar photovoltaic electricity in general. SPV electricity is most suitable for areas where it is difficult to ensure the availability of standard grid electricity reliably and at reasonable costs. Some major

advantages of SPV energy systems are listed below:

- ## SPV energy systems work absolutely noiselessly. You may well notice this during the operation of your pumping system. Unlike a diesel pump set, your SPV pumping unit does not make any noise at all. It also will not produce any pollutant or exhaust like a diesel pump set. The SPV systems also do not produce any ecological or environmental imbalance. In fact, the SPV arrays may turn out to be aesthetically appealing to many.
- ## Your SPV pumping system should require minimal maintenance. The small amount of preventive maintenance requirements, such as the cleaning of the array surface, should not be a difficult task. Your system should work effectively almost without any attendance.
- ## Your pumping system is totally Self-Reliant and Stand-Alone. It should be easily installed in the shortest possible time. This is a feature which is attractive from the point of view of providing independent electrical energy to pump water in places where water cannot be provided otherwise.

The installation and operation of your SPV pumping system is very simple. Once you have the system in your possession, you do not have to depend on outside sources for the supply of energy. The pump installation time is short. Thus the gestation period is very short.

Your pumping system has been designed for a specific purpose of pumping water from a total head of 20 metres. An optimum balance has been introduced between the water requirement and the capacity of the energy source. Thus the wastage of energy is minimized.

As stated earlier, your SPV pumping system is backed by excellent solid-state reliability and effectiveness. This feature is extremely important for places where maintenance help is just not available.

Finally, the only "fuel" required to operate your SPV pumping system is sunlight. Your system should work more efficiently at low and moderate ambient temperatures and under high solar radiation.

2.8 Disadvantage

Inspite of many advantages and excellent features of your solar photovoltaic water pumping system, there is one major disadvantage. Presently, your pumping system is rather expensive.

Your pumping system has been donated by Mr. Dominique LaPierre, the author of "The City of Joy". In addition, there are other expenses to be borne to transport, install, operate and maintain your pumping system. Therefore, it will be imperative on your part to ensure that the pumping system is utilized to the maximum extent feasible. It should run every day. If water is not required for certain days, it could be stored for use later.

Please do not think that if your pumping system is run every day, it might break down soon. That is not the case. In fact, such pumping systems are designed to operate for all days of the year, when the sunlight is sufficient to run them.

For far-flung areas in a country like ours, where it will be ages before grid-electricity from centralized power stations can be taken, SPV pumping systems should turn out to be highly attractive.

Annexure 2 C

Manufacturer's Specifications



PHOTOWATT
INTERNATIONAL S.A.

INSTALLATION NOTICE FOR

32 SOLAR MODULES SUBMERSIBLE PUMP

PHOTOWATT

PART LIST

(8 FRAMES)

- 32 Solar modules
- 16 Modules aluminium supports
- 4 Cabling kits
- 9 Support feet U shape
- 16 Tilt adjustment rods
- 1 Connection box with serie
- 1 Inverter cabinet
- 1 Support of cabinet
- 1 3x80 submersible electric motor
- 1 Outlet hose (fitted with above)
- 1 Submersible cable (fitted with above)
- 1 Well head (fitted with above)

OPTIONS

- 1 Set of nuts and bolts

LIST OF TOOLS NECESSARY FOR THE INSTALLATION

CIVIL WORK

Compass, tracing-line,
Shovel, pickaxe,
Spirit level, decameter,
Concrete.

FITTING AND CONNECTIONS

2 or 4 13 mm wrenches, 2 10 mm wrenches, 1 17 mm wrench,
Cruciform screw driver,
Small and medium flat screw drivers,
Knife, wire stripping plier,
Plier, cutting plier,
Voltmeter (0-20 and 0-200 V DC),
Hammer.

1 - DESCRIPTION

The 16-40 solar pump range include three main elements :

- the photovoltaic generator,
- the inverter,
- the submersible electropump unit,

1 - 1 - the photovoltaic generator

The standard peak powers of the generators are 640 , 960 , 1280 and 1600 Wp.

The modules are fixed by frames of 4 and enchoed on the ground by support feet made with aluminum (see drawing).

The 16-40 range needs a number of 8 modules in series, so a paire number of frames (4, 6, 8, 10).

The frames have an adjustable tilt angle according to the latitude of the site

1 - 2 The inverter

The inverter has been specially designed for "pumping " following the sun ".

It transforms the direct current from the photovoltaic generator to variable frequency alternative current ; this frenquency is related to the insolation .

Its main characteristics are :

adjustable inlet voltage	: 100 to 120 volts
outlet voltage	: 80 V at 60 Hz
variable frequency	: 0 to 60 Hz
protections	: polarity inversion , overload or short circuit on output .

In the other hand, the inverter also secures the " lack of water" function in the bore-hole and stops the pump, should the water level in the bore-hole be too low : the inverter protects the pump.

Optional : a "full tank" electronic card, connected with a float switch. It stops the pump when the storage tank is full .

I-3 The electropump unit

It is a 4" submersible pump

- the hydraulic part is multistage centrifugal. The number of stages is related to well characteristics (TMH)
- the motor is threephase AC (brushless, maintenance free).

II - INSTALLATION

II-1 Foundation

The frame supports have been designed to simplify the civil work

II-1-1 Site selection

A flat area must be selected in order to reduce the work.
In no case the site should receive any shade from surrounding trees, houses, or elevated tank. The frames should see an open sky.

CAUTION : take into account seasons when the sun is low on the horizon to be sure to be away from any shadow.

II-1-2 Civil work

Drawings for civil work are given in appendix

CAUTION : carefully respect the gap between feet
Fix the support feet with the two wings of the U shape facing South in northern hemisphere.

II-2 Fitting

II-2-1 Fitting of the generator

The frames are fixed by 2 central bolts, nuts and large washers.
(see the drawing)

CAUTION : carefully place all the panels in order that the connexion boxes are on the same side. The adjustment rods have several holes which allow to tilt the frame with an angle from 10 to 40°. Choose an angle close to the latitude of the site. It is possible to have a negative tilt by placing the adjustment rods on the other side of the frame feet.

N.B. : The frame must face south for northern hemisphere, and face north in southern hemisphere. (See detailed fitting drawing).

II-2-2 Fitting of the electropump unit (see drawing)

- Introduce the pump in the bore hole, slowly.
Be careful to the electric cable, in order not to damage it.

III - ELECTRICAL CONNECTIONS

III-1 Fixing of the cabinet and the connection box

- Fix the connection box on a frame foot in the middle of a row (to take full benefit from the frame shadow) and toward the bore-hole (see fixation drawings).
- Fix the inverter cabinet on one foot near the bore-hole. See fixation drawings.

III-2 Cable connections

NOTA : Do the electric connections early in the morning or in the evening to avoid electric shock.

See the general cable wiring and proceed as follow :

- Connect the small cables between solar modules (7 pieces, in order to connect 8 modules, or 2 frames in serie)
- Adjust the lenght of the output cable, between output of solar row and junction box (do not hesitate to be generous and not to cut too short!)
- Strip off the end of the cable (which has no fast-on lugs);
- Connect each output cable in the junction box
- Check that the cabinet is switched off,
- Connect the connection box to the inverter cabinet starting by the cabinet side and using the 2 x 6 mm² cable,

- connect the pump cable on the three terminals of the inverter cabinet and follow the NO. marked on each side. The pumping system is ready for operation. Carefully check all the connections in order to avoid any bad connections or connection faults.
- switch on the cabinet, after a few moment water should pour out from the pipe,
- check the flow : should this on seem weak or null, then stop the system and invert any 2 wires of the pump cable in the cabinet (the motor has been turning the wrong way),
- switch on again and mesure the new flow. The bigger flow corresponds to the right rotation way, so to the right connection.

IV - RECOMMANDATIONS FOR THE OUTLET PIPE

Size : use pipe of 2" diameter (or bigger).

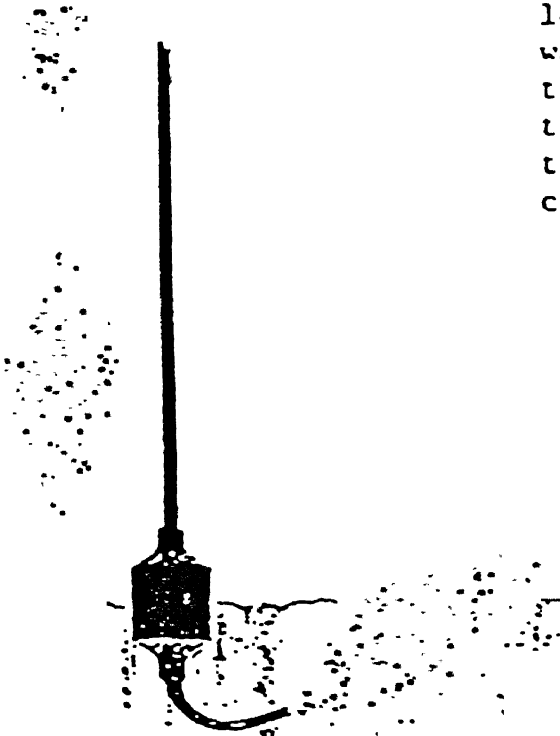
Fittings : use a minimum of elbows (2 only if possible) do not put any valve nor check valve. If needed, fix a watermeter on the outlet of the tank and not along the pipe from pump to tank.

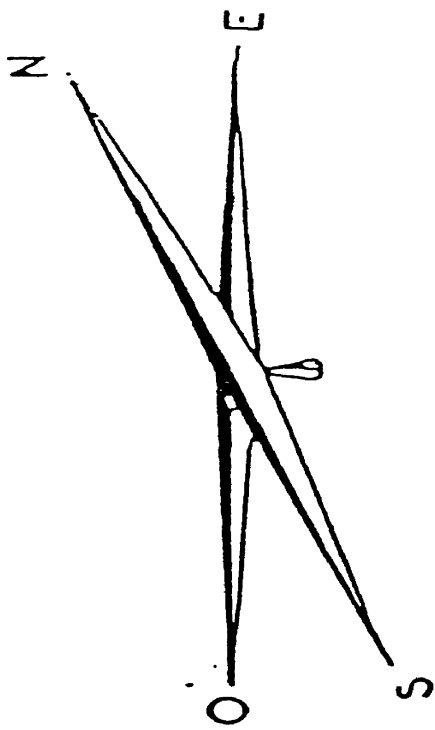
Piping : try to fix the pipe slightly rising from the bore-hole head up to the tank in order to avoid any air blockage in the pipe (losses of charge).

In any case try to avoid any losses of charge along the piping, in order to get the full flow from the pumping system.

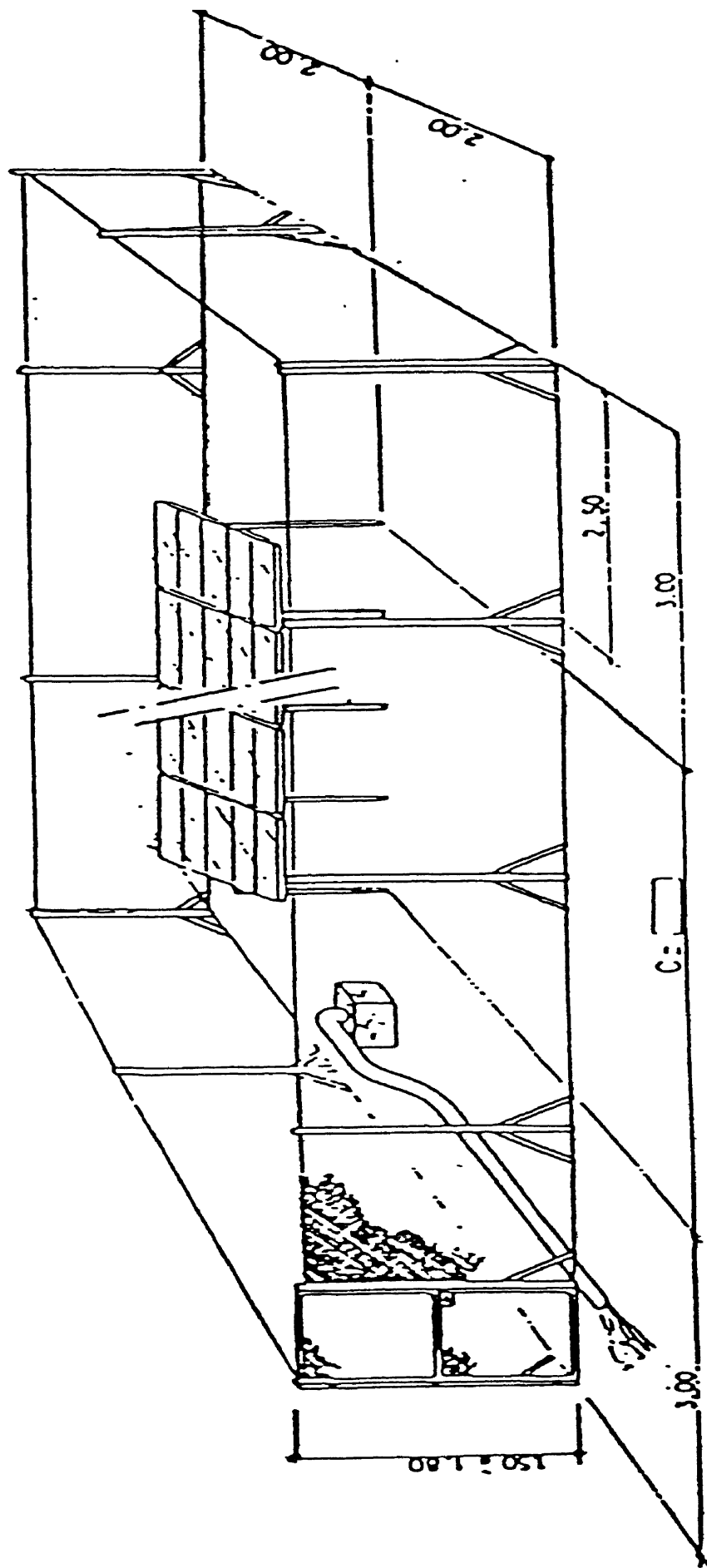
TANK FULL STOPPING DEVICE (OPTION)

Fix the floating switch in the tank. The lead weight position set the level of water where the pump will stops. Connect the 2 wires of the cable in the 2 connectors of the cabinet (no polarity). In case the function is not needed, leave the connectors free.





INSTALLATION TYPIQUE
TYPICAL INSTALLATION



SUD



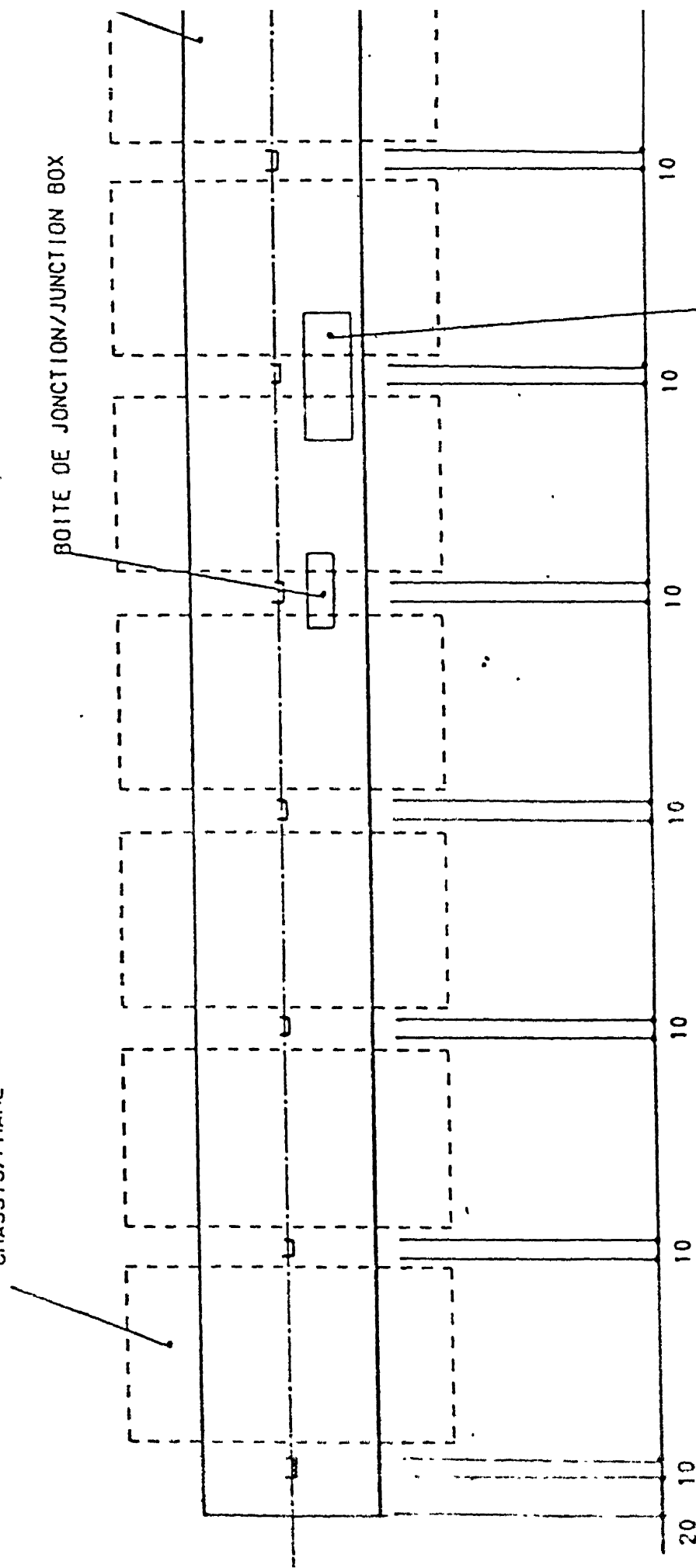
VUE EN PLAN / FLAT VIEW

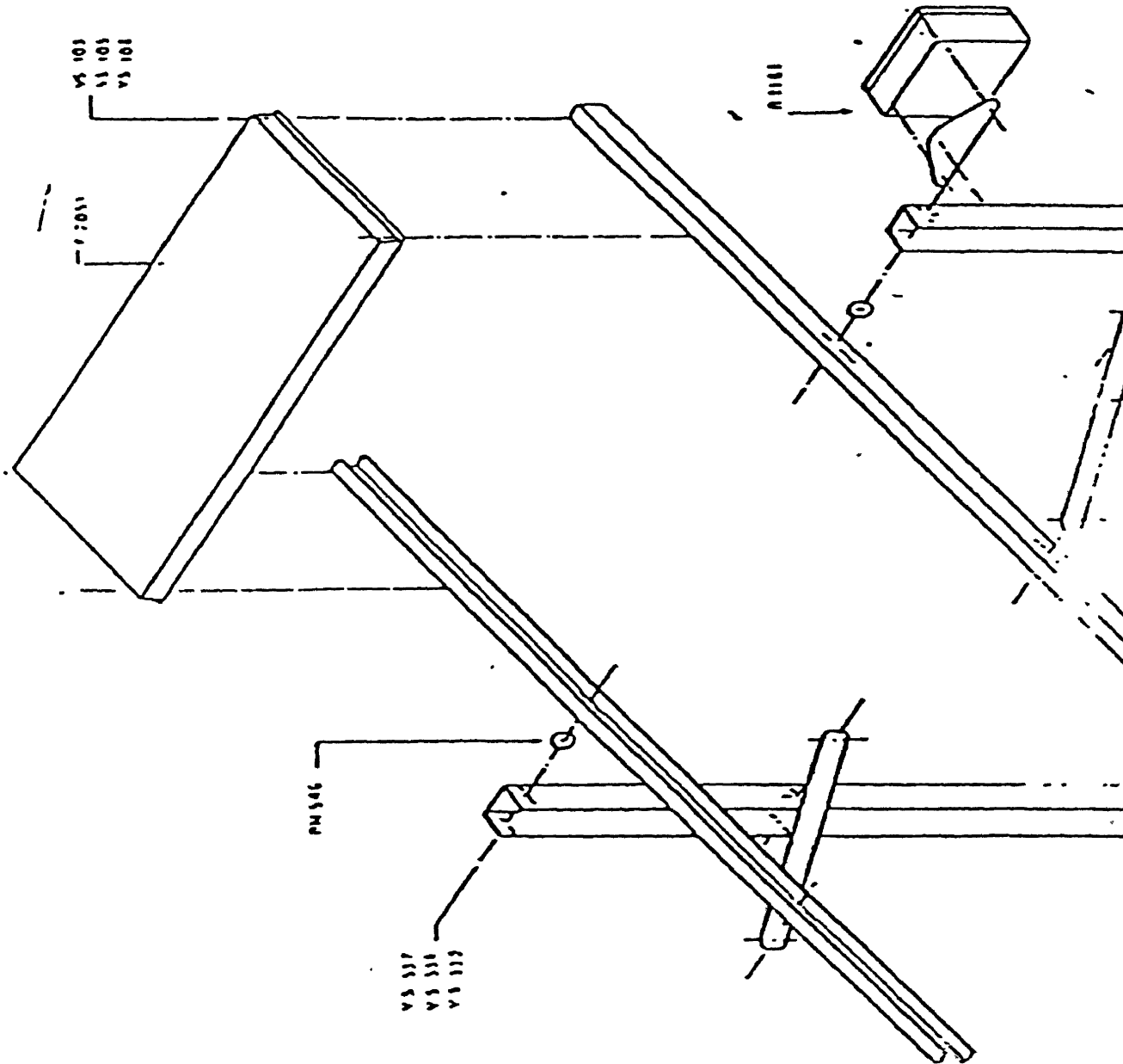
CHASSIS/FRAME

BOITE DE JONCTION/JUNCTION BOX

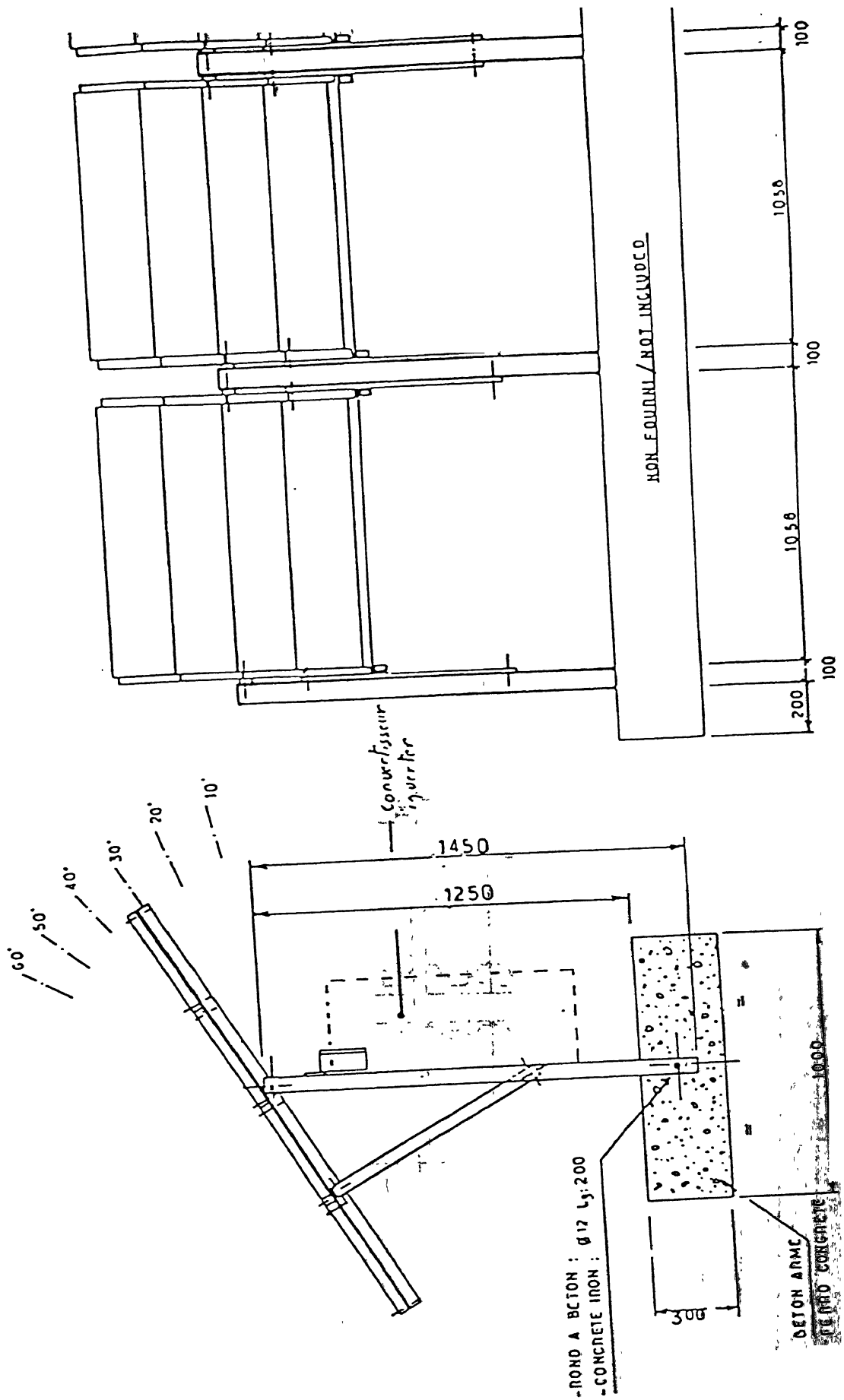
8 x 105.8 cm

ARMOIRE REGULATION
CABINET REGULATION



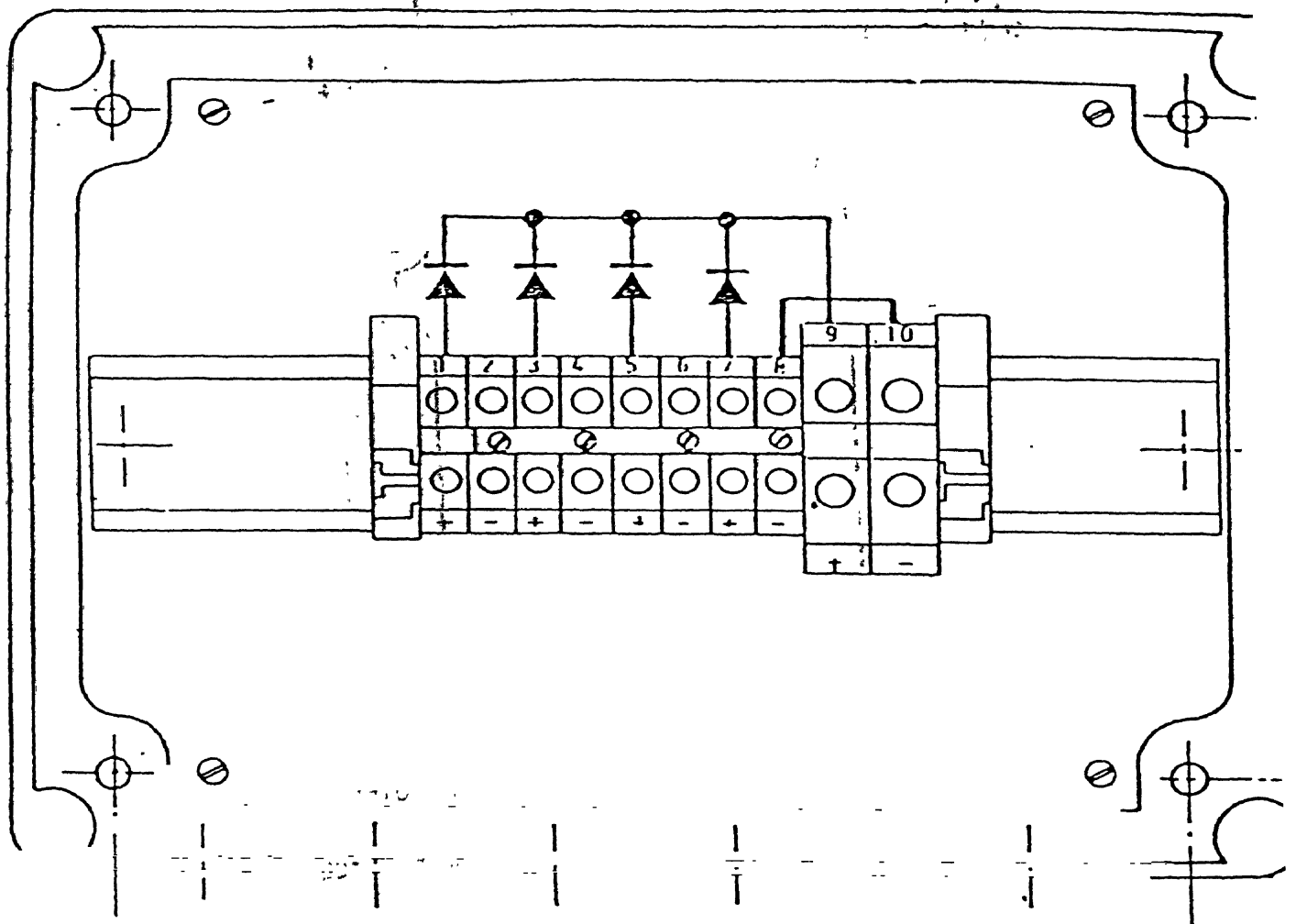


REP	DESIGNATION
R2051	MODULE. SOLAR PANEL BPX 47 402
PR509	PROFILE STRUCTURAL U80x50x5 ALU. N.300 927
PR510	MEPLAT FLAT 40 x 6 ALU. N.300 926
PR511	PROFILE STRUCTURAL 50 x 30 x 4 ALU; N.300 928 1
R1161	BOITE DE JONCTION + ACCESSOIRES JUNCTION BOX + ACCESSORY N.300 287
PM546	ENTRETOISE BRACE N.400 231 ALU.
VS103	ECROU NUT HUB ALU.
VS105	RONDELLE WASHER M6 ALU.
VS106	VIS SCREW T10x20 ALU.
VSS37	VIS SCREW T10x40 INOX
VSS38	ECROU NUT M12 INOX.
VSS39	RONDELLE WASHER M12 INOX.



CHASSIS FRAME	4 MV 2P	3	Modif	Date	Page
		2			
PHOTOWATT INTERNATIONAL SA	Designé	Echelle	Date	Page	2

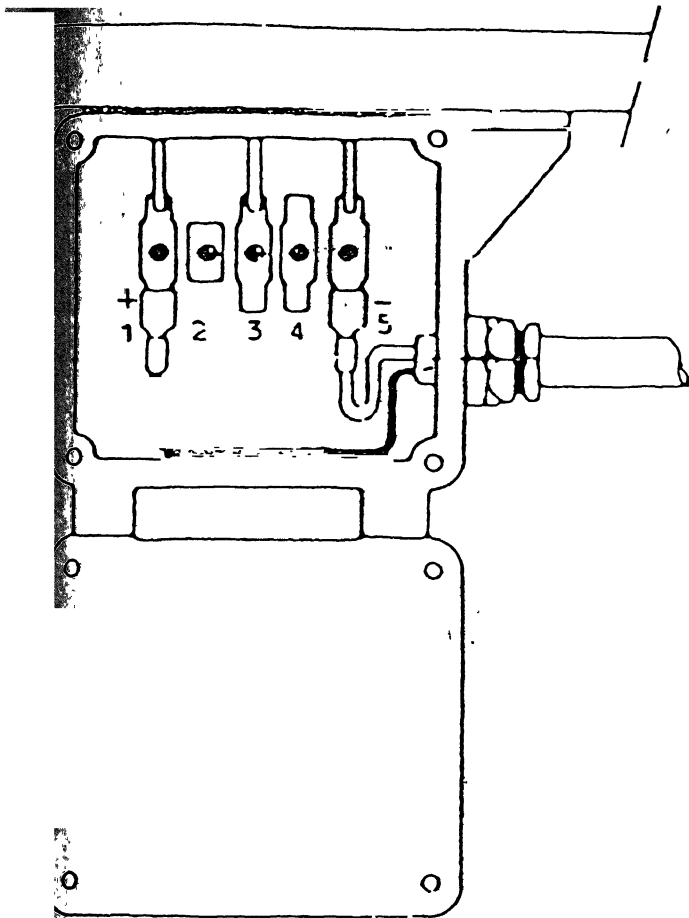
BOITE DE JONCTION / JUNCTION BOX



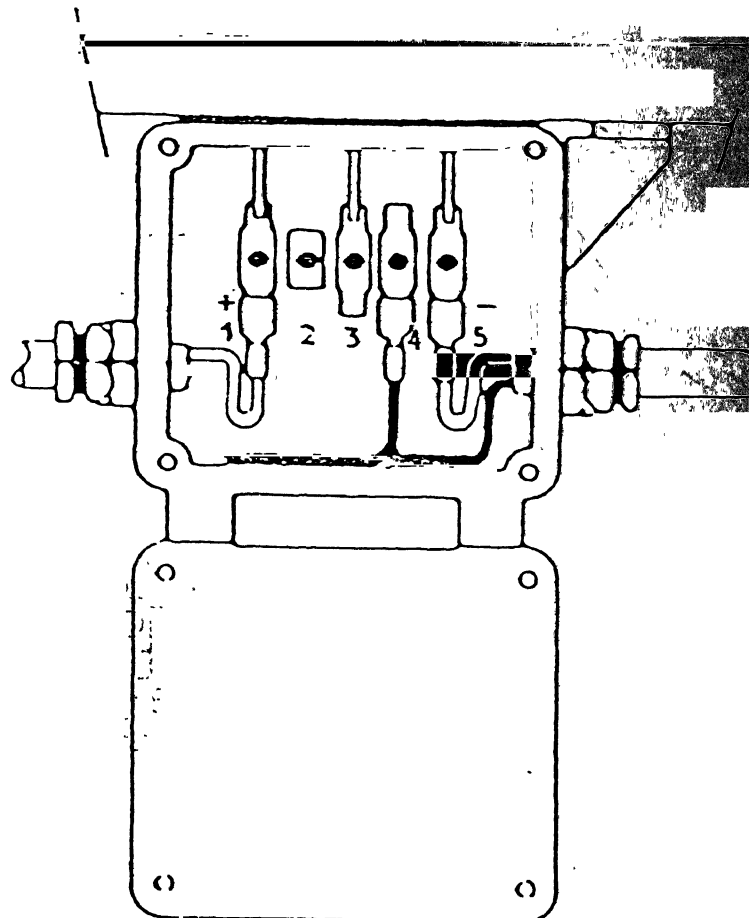
ENTREES SOLAIRES
SOLAR INPUTS

VERS ONDULEUR
TO INVERTER

SOLAR MODULES CONNECTION



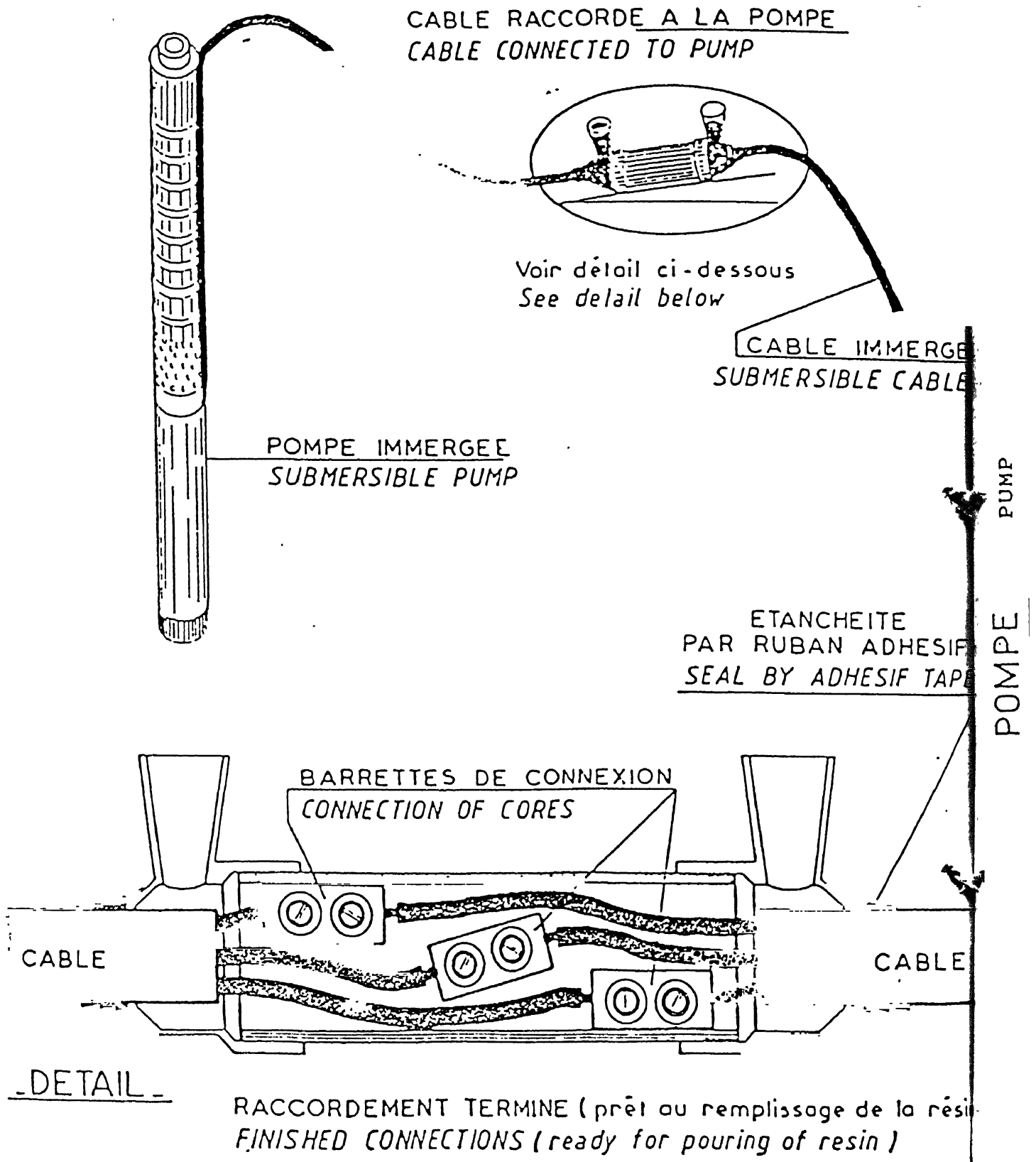
BEGINNING OF "SERIE" CONNECTION



ALL OTHER CONNECTION BOXES

OF THE "SERIE" (7 BOXES)

PREPARATION DU RACCORDEMENT DU CABLE IMMERGE SUR SITE AVEC TROUSSE A' EPIS - SURE / SEALED CONNECTION OF ELECTRIC SUBMER- SIBLE CABLE BY THE SPLICING KIT



90° ELBOW
(large radius)

COUDE 90°
(grand rayon)

well
head

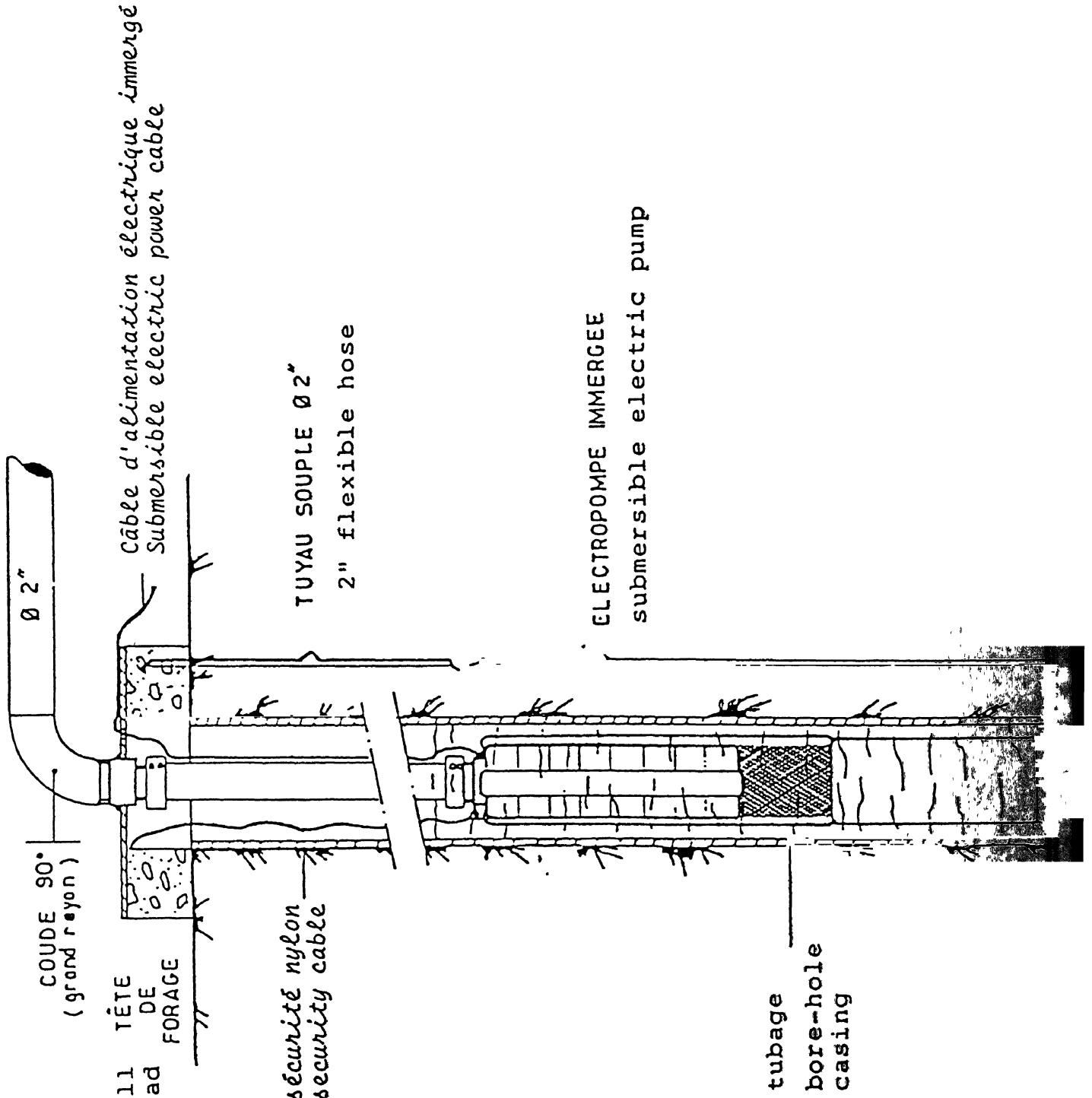
TÊTE
DE
FORAGE

Câble sécurité nylon
Nylon security cable

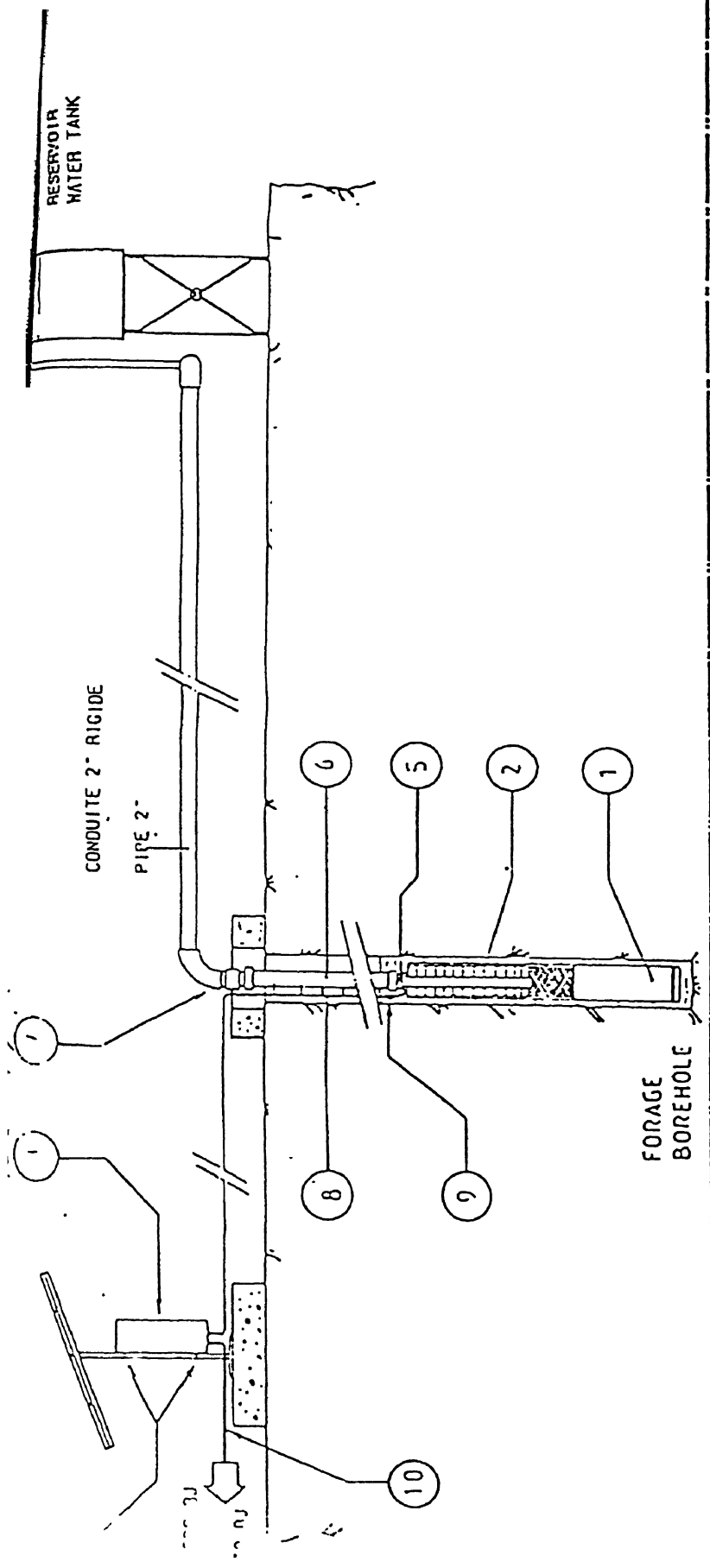
TUYAU SOUPLE Ø 2"
2" flexible hose

ELECTROPOMPE IMMERGEE
submersible electric pump

tubage
bore-hole
casing



1	2	3
Modification		
Version		
Echelle		
Date	Date	Date
Pat	Pat	Pat
N° de dessin		



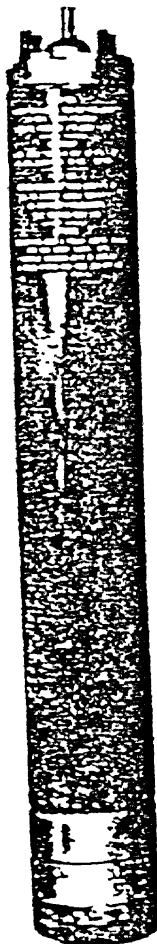
1. AC MOTOR
2. MULTISTAGE CENTRIFUGAL PUMP
3. INVERTER AND SWITCH
4. FIXATION FITTINGS
5. PIPES CONNECTORS
6. FLEXIBLE TUBE
7. BOREHOLE HEAD
8. WATERPROOF CABLE
9. CABLE CONNECTORS
10. CABLES

DOCUMENTATION TECHNIQUE

TECHNICAL BROCHURE

MOTEURS IMMERGÉS 4"

SUBMERSIBLE 4" MOTORS



**LEROY
SOMER**

DÉPARTEMENT DE RECOUPE
16800 SOYAUX - FRANCE
TÉL. : (45) 92.92.11
TÉLEX : 790216

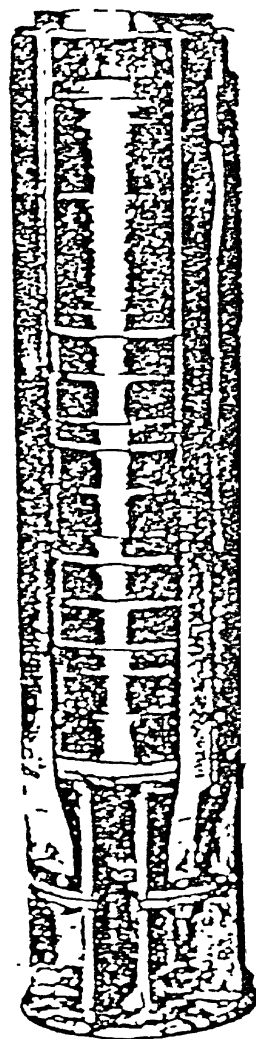
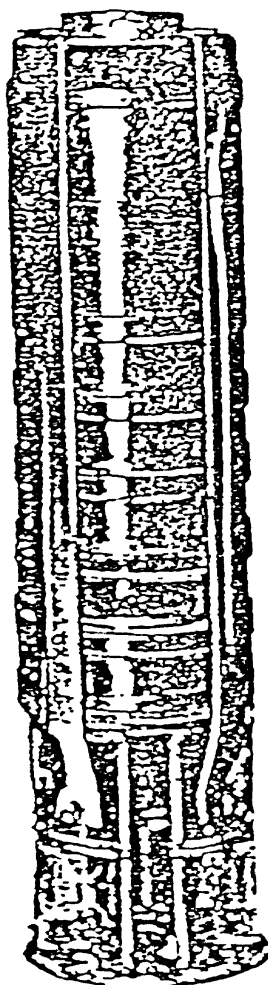
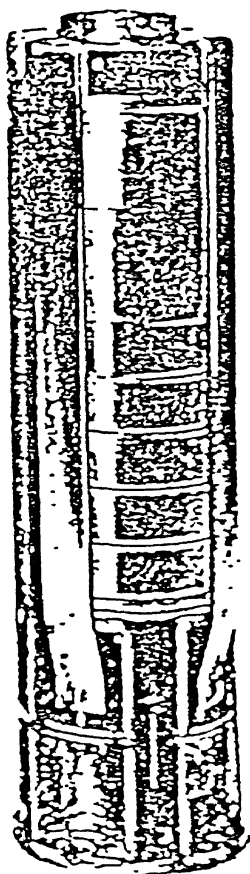
DOCUMENTATION TECHNIQUE

TECHNICAL BROCHURE

SUBMERSIBLE 4" PUMPS

HYDRAULIQUE

4"



DÉPARTEMENT
16800 SOYAUX -
Tél : (01) 9...
Tél : (01) 9...



PHOTOWATT
INTERNATIONAL SA

INVERTER

TECHNICAL SPECIFICATIONS NOT AVAILABLE

Annexure 2 D

SITE SELECTION CRITERION

SITE :

1. Need for average 35 M^3 water per day Y/N

2. Whether land selected for the installation is community land Y/N

3. Details of the well
 - a) type borewell/openwell
 - b) yield
 - c) water depth

4. Details of the location of the array (land & surroundings).

5. Weather characteristics

6. Details of water management

a) distance and slope of the point of utilization of water from the pump

b) distribution network proposed (pipes/channels etc.)

c) storage tank

d) Waste water utilization

7. Social structure of the village and infrastructure available for installation, monitoring and maintenance of the system

8. Level of user participation in the local management of the project

Annexure 2E

Material Required for PV Pump Installation

1. Cement	5 bags
2. Gravel	1/4 trolley
3. Sand	1/4 trolley
4. Bricks	1000
5. Prismatic Compass	1
6. Ranging Rods	4
7. Limestone Powder	1 kg
8. Dumpy Level	1
9. Cross Staff	1
10. Spades	4
11. Shovels	4
12. Cruciform Screw Driver Set	1
13. Screw Drivers	3
14. Pliers (Insulated)	1
15. Nosed Pliers (Insulated)	1
16. Wire Insulation Remover/Blades	1
17. Hammers	2
18. Pickaxes	4
19. Crow-bars	3
20. Spanner Sets	2
21. Loose Nuts & Bolts (Different Sizes)	1 set
22. Pipe Wrenches	3
23. Vice	2
24. 2" Bends	3
25. 2" G.I. Pipe	1 length

26. Hack Saw	2
27. Pipe Threading Machine	1
28. Adjustable Spanners	2
29. String	1 roll
30. Measuring Tape	30 m
31. 2" Water Meter	1
32. Fencing Material	for a perimeter of 20 x 20 m
33. Insulation Tape	1 roll
34. Teflon Tape	3 rolls
35. Multimeter	1
36. Insulated Copper Wires	10 m
37. 2" Couplings	4
38. Plumb Line	1
39. Truck/Vehicle	2

Manpower Requirements

1. Mason	1
Helpers	3
2. Plumber	1
Helpers	3
3. Electrician	1
Helpers	2
4. Surveyor	1
Helper	1

Annexure 3.A

TATA ENERGY RESEARCH INSTITUTE NEW DELHI

RECORD SHEET on

SPV PUMPING SYSTEM

Organisation :

Place :

Month :

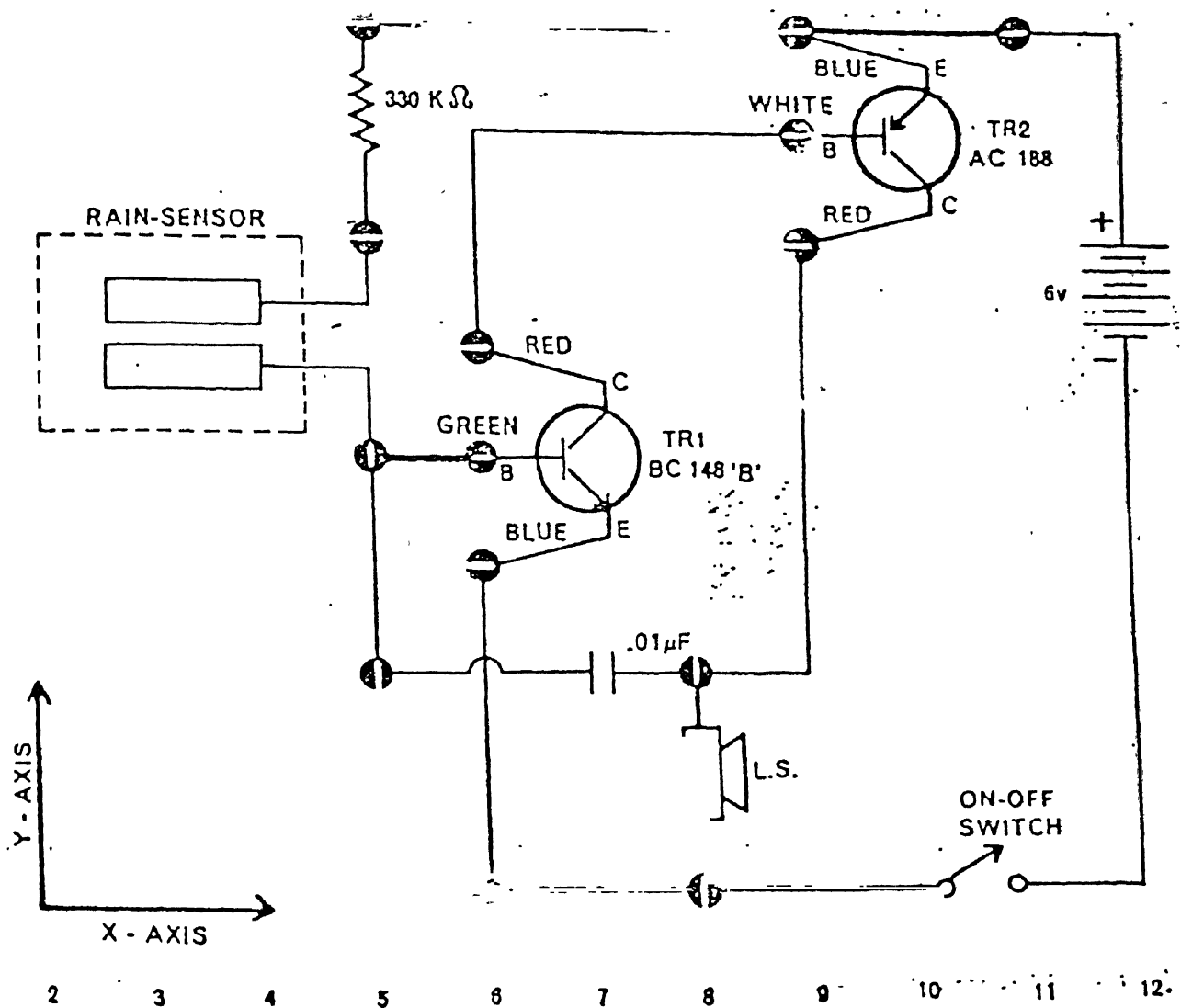
19__

Date	Water Meter Reading	Signature of Recorder	Date	Water Meter Reading	Signature of Recorder
1			17		
2			18		
3			19		
4			20		
5			21		
6			22		
7			23		
8			24		
9			25		
10			26		
11			27		
12			28		
13			29		
14			30		
15			31		
16					

PLEASE ENSURE THAT WATER-METER READINGS ARE TAKEN
AFTER THE PUMP STOPS PUMPING WATER

either in the same evening, or early next morning before
pumping starts again.

Due to some unavoidable reasons, you may not be able to take meter-reading on one or two days. In such cases, please do not fill in that day's (or, those days') records. However, please ensure that, as far as possible, readings are taken every EVENING after the pumping stops, or EARLY NEXT MORNING before the pumping starts again.



Instrumentation

1. Integrating Quantum radiometer/photometer : Model L-188 B manufactured by LI-COR Inc. was used to measure solar irradiance on the plane of the array. For measuring solar intensity, the instrument uses a silicon cell pyranometer mounted on a base with a spirit level. The instrument can integrate value up to 1000 seconds. Normal readings, are provided for 1 second integrating period.
2. Power multiplier 3B : Manufactured by Asterline Angus Instruments corp, USA, the instrument was used to measure AC power output from the inverter. The instrument can measure both 3 phase and single phase balance and unbalanced load, voltages and currents in all phases (maximum range 600 V and 1000 Ams respectively), KW, KVAR and KVA (active, reactive and apparent power). It can also integrate these values to give kWh, KVARh and KVAh respectively.

The instrument also has capability to measure motor-in-rush current and peaks and valleys in measured values. The instrument incorporates clip-on type current transformer for making on load measurements without disrupting power supply.

3. Autoranging Digital multimeter : Model 2100 from Hindustan Instruments Ltd. (HIL) was used to measure both voltage and current at various points. The instrument offers a range of 200 mA - 10 A for current measurement (both AC and DC) with a resolution of 100 μ A and 10 mA respectively for both the limits. Diode test in the range of 0-2000 mV and resistance measurement from 200 Ω to 20 M Ω .
4. Water table depth measuring instrument : A small instrument based on audio amplifier circuit was developed in TERI to measure the water table depth in the borewell. The circuit is provided overleaf.

Annexure 4 A

Social Impact Assessment

Part A

(organization's response)

Installation/Post installation management (Remarks mostly in Y/N or tick mark)

A. General status :

- | | | |
|------|------------------------------|---------------------|
| i) | Cleanliness of panels | good/fair/poor |
| ii) | Wire connections | loose/connected |
| iii) | Leakage of water | Y/N |
| iv) | fencing for the installation | adequate/inadequate |
| v) | Any other remark | |

B. Maintenance :

- | | | |
|-----|---|--|
| i) | Any responsibility given to any local person(s) | Y/N |
| ii) | Log book | up-to-date/
not complete/
not maintained |

Utilization of Water/Distribution System

- A.
- i) Drinking (no. of people benefitted)
 - ii) Irrigation (area of land)
 - iii) Any other
 - iv) Waste water

- B.
- i) Brief description of the distribution system

Problems encountered

- i) Any failure/problem observed. If yes, then details of problem, period of occurrence, trouble shooting done, etc.

ii) Overall performance as observed by the organization.

Annexure 3 C

Performance evaluation (Technical)

Date _____

Village

Organization

Tilt angle for the array

Time period of the experiment

Pumping head

[illegible]

Annexure 4B

Part B

User's Response

- a) Name, age and educational qualifications of the person
- b) Family size
- a) On an average how much water does his family get daily?
- b) How is the water utilized?
- c) What was the source of water before SPVWPS?

Is there any saving in terms of Time/Labour (human + cattle)/money after SPVWPS was commissioned?

- a) T / L / T+L
- b) How is it utilized?

Based on the user's observation on the performance of SPVWPS and its approximate cost, how is it ranked as an alternative technology?

- a. for supplying potable water to villages, good/fair/bad
- b. for personal use. Y/N, if yes, at what cost?
 - (i) at 5 times (ii) at 4 times (iii) at 3 times
 - (iv) at 2 times (v) at par with the cost of conventional pump
- c. for rural development (as a panch)

Any other remark (whether some more such system should be provided, better distribution network, etc.)

Annexure 4 C

PUBLIC HEALTH ENGINEERING DEPTT. MANDALGARH

1)	Tube Well Dia 165 mm, Total depth = 90 m Discharge = 10,000 lph. Total expenditure incurred	= Rs.21700.00
2)	R.C.C. G.L.R. 50,000 litres capacity	= Rs.48500.00
3)	Boundary Wall including cost of refilling and levelling of site	= Rs.35000.00
4)	Construction of C.C. foundation blocks	= Rs. 1035.00
5)	Cost of G.I. pipes, G.I. specials, valves stand post etc.	= Rs. 3000.00
	Total	----- Rs.109235.00 -----